GHOST VIEW OF WOODS DUAL-POWER CAR, SHOWING LOCATION OF SOURCES OF POWER

Courtesy of Woods Motor Vehicle Company, Chicago, Illinois

Automobile Engineering

A General Reference Work

FOR REPAIR MEN, CHAUFFEURS, AND OWNERS; COVERING THE CONSTRUCTION, CARE, AND REPAIR OF PLEASURE CARS, COMMERCIAL CARS, AND MOTORCYCLES, WITH ESPECIAL ATTENTION TO IGNITION, STARTING, AND LIGHTING SYSTEMS, GARAGE DESIGN AND EQUIPMENT, WELDING, AND OTHER REPAIR METHODS

Prepared by a Staff of

AUTOMOBILE EXPERTS, CONSULTING ENGINEERS, AND DESIGNERS OF THE HIGHEST PROFESSIONAL STANDING

Illustrated with over Fifteen Hundred Engravings

FIVE VOLUMES

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Grateful acknowledgment is here made also for the invaluable co-operation of the foremost Automobile Firms and Manufacturers in making these volumes thoroughly representative of the very latest and best practice in the design, construction, and operation of Automobiles, Commercial Vehicles, Motorcycles, Motor Boats, etc.; also for the valuable drawings, data, illustrations, suggestions, criticisms, and other courtesies.

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WAVERLY FOUR-CHAIR BROUGHAM WITH WIRE WHEELS
Courtesy, The Waverly Company, Indianapolis, Indiana

DETROIT ELECTRIC BROUGHAM

Courtesy of Anderson Electric Car Company, Detroit, Michigan

Foreword

THE period of evolution of the automobile does not span many years but the evolution has been none the less spectacular and complete. From a creature of sudden caprices and uncertain behavior, it has become today a well-behaved thoroughbred of known habits and perfect reliability. The driver no longer needs to carry war clothes in momentary expectation of a call to the front. He sits in his seat, starts his motor by pressing a button with his hand or foot, and probably for weeks on end will not need to do anything more serious than feed his animal gasoline or oil, screw up a few grease cups, and pump up a tire or two.

¶ And yet, the traveling along this road of reliability and mechanical perfection has not been easy, and the grades have not been negotiated or the heights reached without many trials and failures. The application of the internal-combustion motor, the electric motor, the storage battery, and the steam engine to the development of the modern types of mechanically propelled road carriages, has been a far-reaching engineering problem of great difficulty. Nevertheless, through the aid of the best scientific and mechanical minds in this and other countries, every detail has received the amount of attention necessary to make it as perfect as possible. Road troubles, except in connection with tires, have become almost negligible and even the inexperienced novice, who knows barely enough to keep to the road and shift gears properly, can venture on long touring trips without fear of getting stranded. Astonishing refinements in the ignition, starting, and lighting systems

have lately been effected, thus increasing the reliability of the electrical equipment of the automobile as well as adding greatly to the pleasure in running the car. This, coupled with the extension of the electrical control to the shifting of gears and other important functions, has made the electric current assume a position in connection with the gasoline automobile second only to the engine itself. Altogether, the automobile as a whole has become standardized, and unless some unforeseen developments are brought about, future changes in either the gasoline or the electric automobile will be merely along the line of greater refinement of the mechanical and electrical devices used.

¶ Notwithstanding the high degree of reliability already spoken of, the cars, as they get older, will need the attention of the repair man. This is particularly true of the cars two and three seasons old. A special effort, therefore, has been made to furnish information which will be of value to the men whose duty it is to revive the faltering action of the motor and to take care of the other internal troubles in the machine.

¶ Special effort has been made to emphasize the treatment of the Electrical Equipment of Gasoline Cars, not only because it is in this direction that most of the improvements have lately taken place, but also because this department of automobile construction is least familiar to the repair men and others interested in the details of the automobile. A multitude of diagrams have been supplied showing the constructive features and wiring circuits of the principal systems. In addition to this instructive section, particular attention is called to the articles on Welding, Shop Information, and Garage Design and Equipment.

¶ For purposes of ready reference and timely information so frequently needed in automobile operation and repair, it is believed that these volumes will be found to meet every requirement.

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*For page numbers, see foot of pages.

†For professional standing of authors, see list of Authors and Collaborators at front of volume.

RAUCH AND LANG ELECTRIC COACH

Courtesy of Baker R. and L. Company, Cleveland, Ohio

ELECTRIC AUTOMOBILES

PART I

INTRODUCTION

The electric automobile was the natural and logical outgrowth of the storage-battery street car, which, in the early 90's, was looked upon as having a great future of commercial utility. That electric vehicles were being manufactured and marketed on as general a scale as the radical nature of the innovation would permit, as early as 1897, is accordingly not surprising. The first step away from the time-honored horse-drawn hack was the electric cab, a number of which were placed in service on the streets of New York City as early as 1899.

Essential Features. At first the electric vehicle marked the closest approach to the "horseless-carriage" ideal so much sought after by builders in the earlier stages of the development of the automobile, and, despite the example and precedents of the gasoline machine, it was in many respects but an advanced replica of the many forms of horse-drawn vehicles that served as its prototypes up to a few years ago. Since then, the electric has been developed along new lines, and, like the gasoline car, is a power-driven vehicle on the design of which the precedents of horse-drawn-vehicle days no longer exert any influence. Its essentials are few in number and simple in construction. They are, first, the storage battery, or source of power; second, the electric motor, forming the medium through which the current is transformed into mechanical energy; and, third, the drive, or means by which the power of the motor is in turn applied to the propulsion of the vehicle. Many works on the subject have assumed a knowledge of the electric motor and storage battery far in advance of that possessed by the average man, and, lacking this, it is difficult, if not impossible, for the uninitiated to appreciate the reasons why certain of the instructions that followed should be rigidly adhered to, while others that were apparently of an equal degree of importance could be slighted with more or less impunity so far as detrimental results were concerned. Without a fundamental knowledge of underlying principles, the electric

vehicle owner or driver must naturally work in the dark, and while blind compliance with the maker's instructions may be faithful at the outset, failure to understand the reasons therefor sooner or later leads to neglect.

Similarity of Types. Though there are quite a number of American-made electric vehicles at present on the market and, while most of them have been manufactured for a number of years, a little study suffices to show that both in principle and construction, the majority of these are very much alike. In fact, the similarity is so great that the beginner will find no difficulty in applying the general knowledge gained from the following pages to any vehicle he happens to possess, or has a chance to examine. There are, naturally, differences in design and in the details by which the power produced at the electrical end is applied to driving the machine. Where these differences are of sufficient importance, they are described in detail, and illustrations of the vehicles and their component parts are given, thus making it easy to distinguish them.

FUNDAMENTAL FEATURES OF THE ELECTRIC

THE STORAGE BATTERY

There is probably no other single electrical device in general use about which there is so much popular misconception as the storage battery, or accumulator, as it is more technically known. It does not in itself create a current of electricity—as does a primary battery, such as the familiar dry cell, in which chemical processes actually generate a current of electricity—and for this reason the storage cell is called a secondary battery. The word *storage* in connection with this type is really a misnomer, as the process by which it absorbs and re-delivers electricity is not one of storage in any sense of the word, but consists of chemical conversion and reconversion upon a reversal of the conditions. As is the case with electric vehicles, there are numerous different forms of storage batteries, for many of which special advantages are claimed; but in general all lead-plate batteries are very much alike, and a description of one will make clear the principles upon which all are based. Theoretically, the principle of the Edison battery is also the same, i.e., that of a chemical reaction upon the passage of the charging current

through the cell and a reconversion upon a reversal of the conditions, but it differs so radically in practice that a detailed description of its construction is given.

CONSTRUCTION AND ACTION OF TYPICAL CELL

General Description. In order to obtain an understanding of just how these processes are carried on, it is necessary to become familiar with the internal action of the cell on receiving and discharging a current and, for this purpose, it is essential to delve into chemistry somewhat. Before taking up this subject, it may be well to mention that *a battery is composed of a group of cells, each of which*

Fig. 1. Typical Battery Plates

is a complete and self-contained unit, though the term battery is indiscriminately applied to both. In a description of its working, a cell is naturally referred to, as all are alike. *A cell consists of two sets of lead grids with pockets so cast in them that what is known as the "active material" may be securely held even in case of severe jolting and vibration.* When filled with the active material, these grids are called plates and are divided into two groups, one positive or + (plus) in character, and the other negative or − (minus), of which typical illustrations are given in Fig. 1. As it is necessary, in order to obtain maximum efficiency, to oppose a surface of negative capacity to each surface of a positive nature, every storage cell will be found to have one more negative than positive plate. It is possible to distinguish them in this manner, where other indications are lacking, but as it is

most essential that they be known, the terminals or connections of the groups are plainly marked by the makers either by the plus and minus signs or in some other equally plain manner, such as painting the positive terminal red. These groups of plates are known as electrodes and are inserted in a jar containing a solution termed the *electrolyte*, which consists of water and sulphuric acid. Fig. 2 shows a sectional view of a small cell.

Electrolyte. The solution in which the elements of the storage battery are immersed, or electrolyte, as it is termed, consists of pure sulphuric acid and distilled, or other pure, water. Concentrated sulphuric acid is a heavy oily liquid having a specific gravity of about 1.835. A battery will not operate if the acid is too strong, and it is therefore diluted with sufficient water to bring it about 1.275 for a fully charged cell. While a battery is being discharged, the electrolyte becomes weaker as part of the acid is combined in the plates in producing the current. This weakening of the electrolyte causes the specific gravity to drop 100 to 150 points during the complete discharge. During the charge, this acid is returned to the electrolyte, thus increasing its strength until it again reaches the normal gravity. There being no loss of acid, it is never necessary during the normal service of a battery to add any acid to the cells.

Fig. 2. Assembled Storage Cell

Unless acid is actually known to have been lost out of a cell, none should ever be added during the entire life of the battery.

When the cells have been allowed to gas too freely, for reasons that are explained later, there is more or less spray of acid through the vent holes, but the amount of acid lost in this way is so small as to be entirely negligible. The gravity of the electrolyte need not necessarily be exact, as in a fully charged battery a range of from 1.250 to 1.300 is permissible.

Purity of Acid and Water. Both the acid and the water used in making electrolyte should be chemically pure to a certain standard. This is the same standard of purity in acid as is usually sold in drug stores as "C P" (chemically pure), or by the chemical manufacturers as "battery acid". In this connection, the expression "chemically pure" acid is sometimes confused with acid of full strength, approximately 1.835 sp.gr., and at the same time chemically pure. If this chemically pure acid of full strength be mixed with distilled water, the mixture will still be chemically pure but not of full strength. On the other hand, if a small quantity of some impurity be introduced into the acid, it would not materially reduce the strength, but the acid would no longer be chemically pure.

Determination of Strength of Acid. The usual method of determining the strength of electrolyte is by taking its specific gravity, this method being possible because of the fact that sulphuric acid is heavier than water. Therefore, the greater the proportion of acid contained in the electrolyte, the heavier the solution or the higher its gravity. By specific gravity is meant the relative weight of any substance compared with distilled water as a basis. Pure water, therefore, is considered to have a gravity of 1. An equal volume of chemically pure sulphuric acid weighs 1.835 pounds. It, therefore, has a specific gravity of 1.835 and is referred to as "eighteen thirty-five". As it is customary to carry the gravity readings out to three decimal places, the gravity of water, which is 1, is written 1.000 and is spoken of as "one thousand". These specific gravity readings are usually taken by means of a hydrometer, shown in Fig. 3 and discussed latter.

Temperature Correction. Since the electrolyte, like other substances, expands when heated, its specific gravity is affected by a change in temperature. If electrolyte has a certain specific gravity at 70° F. and is then heated, the heat will cause the electrolyte to expand, and although the actual strength of the solution will be the same as before heating, yet the expansion will cause it to have a lower specific gravity, the difference amounting to approximately one point (.001) for each three degrees rise in temperature. For instance, if electrolyte has a reading of 1.270 at 70° F. and the temperature be raised to 73° F., this increase in temperature will expand the electrolyte sufficiently to drop its gravity from 1.275 to 1.274. On the other

TABLE I

Sulphuric-Acid Solutions*

Based on one part acid of 1.835 sp. gr. at 60° F.

Specific Gravity of Solution (70° F.)	Parts of Water to One Part Acid		Percentage of Sulphuric Acid in Solution
	By Volume	By Weight	
1.100	9.8	5.4	14.65
1.110	8.8	4.84	16.
1.120	8.	4.4	17.4
1.130	7.28	3.98	18.8
1.140	6.68	3.63	20.1
1.150	6.15	3.35	21.4
1.160	5.7	3.11	22.7
1.170	5.3	2.9	24.
1.180	4.95	2.7	25.2
1.190	4.62	2.52	26.5
1.200	4.33	2.36	27.7
1.210	4.07	2.22	29.
1.220	3.84	2.09	30.2
1.230	3.6	1.97	31.4
1.240	3.4	1.86	32.5
1.250	3.22	1.76	33.7
1.260	3.05	1.66	35.
1.270	2.9	1.57	36.1
1.280	2.75	1.49	37.3
1.290	2.6	1.41	38.5
1.300	2.47	1.34	39.65
1.320	2.24	1.22	42.
1.340	2.04	1.11	44.1
1.360	1.86	1.01	46.3
1.380	1.7	.92	48.4
1.400	1.56	.84	50.5
1.450	1.25	.68	55.5
1.500	1.	.55	60.15
1.550	.8	.44	64.6
1.600	.639	.348	69.12
1.650	.497	.27	73.32
1.700	.369	.201	77.6
1.750	.248	.135	82.1
1.800	.1192	.0646	87.5
1.835	0.	0.	93.19

* Courtesy of *Electric Storage Battery Co.*

hand, if the temperature had dropped to 67° F., this would have caused the gravity of the electrolyte to rise to 1.276. Since change of

temperature does not alter the strength of the electrolyte but merely changes its specific gravity, the gravity reading should be corrected one point for every three degrees change in temperature. For convenience, 70° F. is considered normal and is the point from which corrections are made. This refers to the temperature of the electrolyte itself and not to that of the surrounding air. Table I shows the parts of water by volume, the parts of water by weight, and the percentage of acid to water to produce different specific gravities.

Replacing Evaporation or Other Losses. The electrolyte, or solution, in the cell consists of a mixture of sulphuric acid and water; the sulphuric acid does not evaporate, but the water does. When the level of the electrolyte becomes low, it is due under normal conditions to the evaporation of water, and this loss should be replaced with water only. There being no loss of acid, it is never necessary during normal service to add any acid to a battery. Of course, if a jar is upset and acid spilled, or if a jar breaks and the acid leaks out, it must be replaced. Care should be taken to see that the cells do not become flooded with water when washing the car; this is apt to short-circuit them across the lead connectors and if it enters the cells to disturb the specific gravity of the electrolyte.

Unless acid is actually known to be lost out of a cell, none should ever be added during the entire life of a battery. The amount of acid lost in the form of spray due to the gassing of the cells is so small that it may be neglected. Only distilled water or other water of approved purity should be used for replacing evaporation. Most natural waters contain impurities, some of which are chemically injurious to the batteries, while others are not. Any water to be regularly used in a garage for battery purposes without distillation should be submitted to the battery manufacturer for approval.

It is necessary that the plates and separators be covered with electrolyte at all times. When adding water, cover the plates about ½ inch. Do not put in more than this amount on the theory that if a little is good more is better, since cells that are over-full tend to slop while the car is running and will also be apt to lose electrolyte while charging, as gassing raises the level of the solution in the cells. Replace evaporation every five to fifteen days, depending upon the conditions of service. The best time for adding water is just before a charge. This may be done most conveniently with the aid of a

syringe of the type ordinarily used with a hydrometer. Keeping the cells filled to the proper level with electrolyte is quite as important as not allowing them to stand discharged for any length of time.

Adjusting the Specific Gravity. The best indication of the condition of a storage cell at any time is the specific gravity of its electrolyte and the treatment to be given should always be governed by the latter. The electrolyte of a fully charged cell of the vehicle type when first put into service should have a specific gravity of 1.270 to 1.280. Although this will change somewhat with age, the battery will continue to give good service between the limits of 1.250 and 1.300. If the gravity should ever rise above 1.300, it should be lowered promptly by replacing some of the electrolyte with pure water. Low gravity in a cell is usually caused by acid being combined in the plates through lack of charge; although, if a jar has been upset and acid spilled, or the jar is leaking, no amount of charging will bring its specific gravity up to the proper point. A decreasing specific gravity in the electrolyte throughout the cells of an entire battery is an indication that sediment is accumulating in the bottom of the jars and that the battery requires washing. This is true, of course, only when the low reading is *not due to insufficient charging.*

Before attempting to raise the specific gravity of any cell by adding acid, charge the battery until certain that a maximum gravity has been reached or, in other words, that no acid is still combined with the plates in the cell. For example, if the electrolyte in a cell should be adjusted to 1.275 when 50 points of acid still remain in the plates, the gravity would rise to 1.325 if the cell were subsequently charged to its maximum.

To adjust the specific gravity to its proper value (1.270 to 1.280), first bring the battery to its true maximum, which can be assured only by charging until there is no further rise in gravity during a period of at least twenty-four hours of continuous charging at about one-half the normal finishing rate. If, after this, the specific gravity is too high, remove electrolyte down to the level of the plates with the syringe and replace with pure water to ½ inch over the plates; if the specific gravity is too low, replace with 1.300 electrolyte, adding it in small quantities to prevent bringing about the opposite condition.

When much adjustment is necessary and facilities are available, as should be the case in a garage handling many electric vehicles,

it is good practice to pour the electrolyte out of the cells into a glazed earthenware vessel or a lead-lined tank, and to raise or lower the specific gravity of this electrolyte as conditions demand. About one-third of the electrolyte is held in the plates and the separators and cannot be poured out, and this should be allowed for in estimating the proper gravity before refilling the cells. In cases where there is a wide variation between different cells, further adjustment may be necessary.

Hydrometer and Its Use. The specific gravity of a liquid is tested by means of an instrument, termed a *hydrometer*, consisting of a weighted glass tube having an appropriate scale. The depth to which this instrument sinks in the liquid to be tested shows its specific gravity by the reading of the scale at the level of the liquid. Fig. 3 shows the several types of hydrometers, while beside each is an enlarged view of the scale. The Type V-1 is more commonly used with electric vehicle batteries, and Type S-1 with starting and lighting batteries. Type M is employed in the battery rooms of central stations where more exact readings are required.

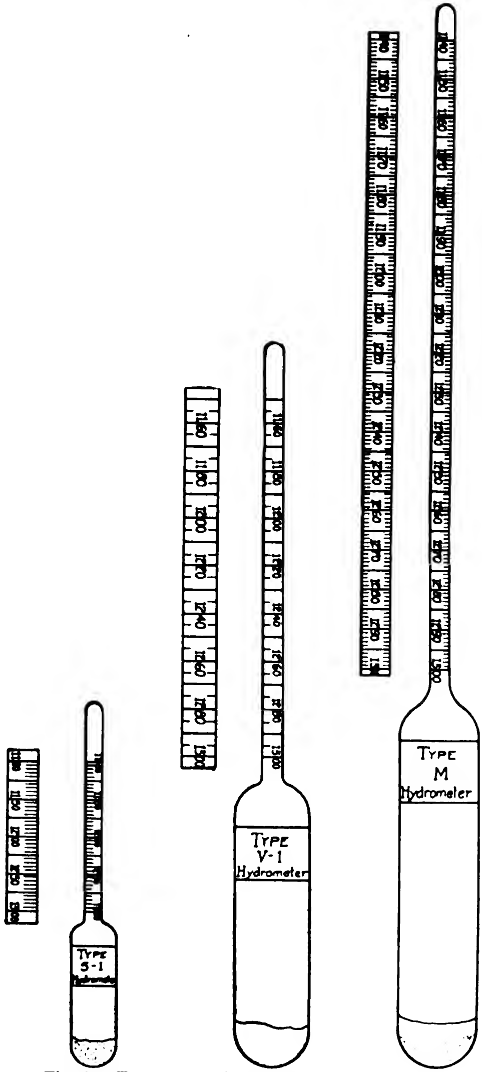

Fig. 3. Types of Hydrometers for Determining Specific Gravity

Where only occasional readings are taken a testing set, such as that shown in Fig. 62, Part II, will serve all purposes, the acid being transferred from the cell to the glass tube by means of the syringe, putting in just sufficient to float the hydrometer clear of the bottom. For constant use in connection with either vehicle or starting and lighting batteries, the type shown in Fig. 61, Part II, is most practical. The readings may be made more rapidly, and there is no danger of spilling acid on the tops of the cells or on the hands. To prevent the hydrometer from sticking to the sides of the barrel, it is necessary to hold it vertically to take the reading. As some of the cells on certain makes of cars are not so situated that the test can be made in this way, the soft-rubber plug in the bottom of the glass barrel is in the form of a trap so that when sufficient acid has been drawn into the barrel, the hydrometer nozzle can be removed from the vent hole of the cell and held in a vertical position, and the acid will not run out while the reading is being taken. Wherever possible, however, the reading should be made without removing the syringe from the vent hole of the cell so that the acid thus withdrawn may be immediately *returned to the same cell.*

Failure to replace the acid withdrawn for a test in the same cell from which it was taken is apt to cause trouble. For example, if acid is taken from one cell, and, after making the reading, it is replaced in another cell, the result is that the amount of acid taken from the first cell is later replaced with water, making the electrolyte that much weaker. Likewise the acid which was put into another cell will make the electrolyte of that particular cell correspondingly stronger, resulting in lack of uniformity of the specific gravity of the electrolyte in the different cells.

To simplify recording the gravity of the cells of a battery it is customary to number them consecutively, beginning with the positive cell in the front compartment of the car and following the cells in the order of the electric circuit. If the trays are removed from the car, this can be accomplished by numbering them in the same order, i.e., beginning with the positive in the forward tray and marking it No. 1 and so on through the entire battery, following the course of the circuit itself.

As soon as sufficient electrolyte has been drawn into the barrel, care being taken to see that the instrument is not sticking to the sides

of the latter, note *underneath the level* of the liquid the graduation on the stem of the hydrometer. Reading the hydrometer by looking at the level of the electrolyte from below is found to be more accurate than looking down upon it from above. By having a gravity-record form tacked on a suitable board and placed on the fender of the car one man can easily take the gravity readings with the left hand and note the results on the form with the right hand, which will avoid spilling acid on the form or, what is more important, on the car itself.

As has previously been explained, the gravity of the electrolyte decreases as the battery is discharged, owing to the fact that a certain percentage of the acid in the electrolyte is absorbed by the plates in producing the current on discharge. In this way, during a normal discharge, the specific gravity drops from 100 to 150 points, depending on the type of cell. Consequently, by noting the gravity of the electrolyte at any time and comparing it with that of full charge, the state of charge can be determined approximately. In the section on "Electrolyte" mention has been made of the fact that the temperature, as well as the proportions of acid and water of which it is composed, also affects the specific gravity of the solution. The gravity of the electrolyte is assumed to be correct when the readings are taken at 70° F. It becomes one point heavier for each three degrees below 70°, and one point lighter for each three degrees above.

For the convenience of the tester, a thermometer has been designed with a special scale opposite the mercury column. This scale corresponds to the temperature scale and indicates at a glance the correction required for the temperature reading. See Fig. 9. Opposite 70° it will be noted that the scale reads zero; above this the correction is plus and below it minus. In making readings, however, it is not customary to note a temperature correction for each, but simply to record the temperature at which the tests are made, and if the variation is sufficient to make the correction important, this is done after all have been taken. The necessary temperature corrections for the specific gravity are given from 30° to 100° F. in Table III, Part II, but in this case the rated specific gravity for various stages of charge is based on a temperature of 80° F. It is immaterial which of these standards is adopted so long as the same one is uniformly adhered to in testing all the cells of the same battery.

A hydrometer test, however, cannot always be considered as conclusive evidence of the condition of a cell. The hydrometer alone may sometimes be a very unreliable guide as to the charged or discharged condition of a cell. For example, if electrolyte or acid had just previously been added to the cell without the knowledge of the tester, the hydrometer reading would apparently show the battery to be fully charged when the reverse might be the case. Consequently, voltage tests must be used in addition as, in the instance just cited, the voltmeter would give an indication directly opposite to that of the hydrometer. Under average conditions, however, the hydrometer alone will closely indicate the state of charge, though it is not to be relied upon in all cases. When there is not enough electrolyte in the cell to make it possible to use the hydrometer for a test, add enough distilled water to restore the normal level and then charge for at least one hour before making the test, as, when recently added, the water will remain at the top of the cell, and the reading thus taken will be valueless. Charging the battery mixes the water thoroughly with the acid of the electrolyte.

Specific gravity readings between 1.275 and 1.300 indicate that the battery is fully charged; between 1.200 and 1.225 that the battery is more than half discharged; between 1.150 and 1.200 that the battery is nearing a fully discharged condition and must be recharged very shortly, as otherwise serious damage will result; below 1.150 that the battery is exhausted and must be recharged immediately.

Variations in Readings. Where the specific gravity in any cell tests more than 25 points lower than the average of the others in the battery, it is an indication that this cell is out of order. Dependence should not be placed, however, on a single reading where there is any question as to the specific gravity. Take several readings and average them. Variations in cell readings may be due to short-circuits inside the cell; putting too much water in the cell, causing loss of electrolyte through overflowing; or to loss of electrolyte caused by a cracked, or leaky, jar. Short-circuits may result from a broken separator or from an accumulation of sediment in the bottom of the jar reaching the plates.

When first testing the cells, low specific gravity in one or more of them may often be equalized by charging, during which frequent readings should be taken at short intervals. If the specific gravity

in any of the cells does not rise to 1.260 after the other cell readings indicate that the battery is fully charged, it is an indication that the low cell is in need of internal adjustment, and it must be dismantled in accordance with the instructions given under that head. See also instructions under "Renewal of an Element" for the method of remedying the trouble.

Quite a substantial percentage of battery troubles—and this is particularly the case with starting-system batteries that are usually neglected until they give out—may be traced to letting the electrolyte get too low in the jars. The effect of this is to weaken the battery, thus causing it to discharge more readily and frequently resulting in harmful sulphating of the plates and injury to the separators. When the latter occurs, it permits the plates to come into contact and causes an internal short-circuit. The importance of always maintaining the level of the electrolyte ½ inch above the tops of the plates by frequent addition of distilled water to bring it up will be evident from this. If, after the occurrence of low cells, the battery does not regain its full efficiency after one or two days, it is an indication that sulphating has taken place, and the remedy as given under that heading should be applied without delay, as letting a battery go without attention in this condition will ruin it.

One of the most frequent causes for low electrolyte in a cell is the presence of a cracked, or leaky, jar, and if one of the cells requires more frequent addition of water to maintain the level of its electrolyte, it is an indication that it is leaking. Unless the jar is replaced immediately, the cell itself will be ruined, and it may cause serious damage to the remainder of the battery. Jars are often broken, owing to the hold-downs becoming loose and allowing the battery to jolt around, or it may be due to freezing. The presence of a frozen cell in a battery shows that it has been allowed to stand in an undercharged condition in cold weather, as a fully charged cell will not freeze except at very low temperatures.

Frozen Cells. In some cases the cells may freeze without cracking the jars. This will be indicated by a great falling off in the efficiency of the cells that have suffered this injury or by a totally discharged condition, which cannot be remedied by continuous charging. In other words, the battery is "dead", and the plates are worthless except as scrap lead. In all cases where cells have been frozen,

whether the jar has cracked or not, the plates must be replaced at once. It must always be borne in mind that low temperatures seriously affect the efficiency of the storage battery and this should be taken into consideration when making hydrometer tests in cold weather. The readings will not be the same in winter as they are in summer for the same condition of charge.

Forming the Plate. The first storage battery, invented by Planté about half a century ago, was composed of nothing more than two plain plates of lead and this solution. When a current is passed through the cell, the acid attacks the lead, depositing on the positive plate lead peroxide (PbO_2) and on the negative plate pure spongy lead. When discharged, the active material changes to lead sulphate on both plates and remains as a thin film of new material on the surface. If this charging and discharging is repeated a number of times, this film gradually becomes thicker. Originally, storage batteries were manufactured in this manner; but the process was a lengthy and tedious one, involving a number of charges and discharges with charges in opposite directions, extending over quite a period, with the result that the active material thus made was loosely attached to the surfaces of the plates and could easily be shaken off. This is known as *forming the plates*, and, naturally, such a cell would not be at all adapted to vehicle work, as the material frequently drops of its own weight and would be instantly shaken off when subjected to vibration. Instead, the plates are cast with the pockets already mentioned, as shown in Fig. 4. This is the Faure, or pasted type of plate, invented in 1881. The material is forced into the pockets under great pressure, so that after the completion of this operation

Fig. 4. Empty Grid

the plate and material are practically integral. Fig. 4 shows an empty grid, and Fig. 5 a completed plate of different make.

Chemical Action on Charging Plate. The number of charges and discharges necessary to fit a cell made in this manner for use is less than by the old forming method. At the beginning of the charge, both plates start as lead sulphate and, combining with the dissociated gases of the water in the electrolyte, are converted into a spongy form of metallic lead at the negative electrode and peroxide of lead at the positive. While an ability to read and understand chemical formulas is not essential to becoming familiar with these processes, a knowledge of the latter is a considerable aid and serves to make them clear with very little study. The fundamental action of the cell, already referred to, is expressed in a short series of equations as follows:

Fig. 5. Complete Battery Plate

CHARGE (read ←←)

(a) $PbO_2 + H_2SO_4 = PbSO_4 + H_2O + O$

(b) $Pb \quad + H_2SO_4 = PbSO_4 + H_2$

DISCHARGE (read →→)

(c) $PbO_2 + Pb + 2H_2SO_4 = 2PbSO_4 + 2H_2O$

(c) = (a) + (b)

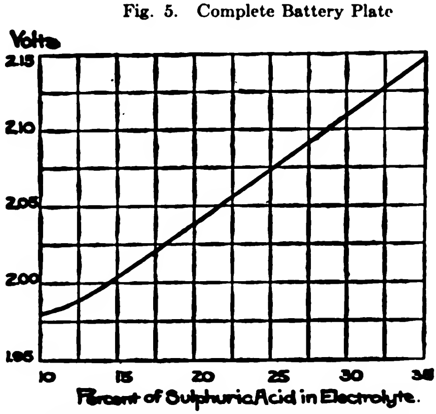

Fig. 6. Variations in Density of Electrolyte with Voltage of Cell

in which (a) is the reaction at the positive plate, (b) the action at the negative plate, and (c) the combined process representing the internal action of the cell on charge and discharge. As the deposit of spongy metallic lead is formed at the negative electrode and the peroxide of lead at the positive, the SO_2 is released and combines with the water in the electrolyte to form sulphuric acid, H_2SO_4. Reading from left to right as indicated for the discharge, it will be apparent that the action consists of the change of lead

and lead peroxide, respectively, on the negative and positive ptales, back into lead sulphate, as well as the reduction of the sulphuric acid to water. The curve, Fig. 6, indicates the difference in the density of the electrolyte, corresponding to the voltage.

Process of Charging. *Precautions Regarding Electrolyte.* To charge, direct current is passed through the cells in the direction opposite to that of discharge. This current passing through the cells in the reverse direction reverses the chemical action which took place in the cells during the discharge. During the latter the acid of the electrolyte penetrates the active material and combines with it, filling its pores with lead sulphate and causing the electrolyte to become weaker. Reversing the current through this sulphate in the plates restores the active material to its original condition and returns the acid to the electrolyte. This is why the battery manufacturer lays such stress on his instructions *never to add acid to the electrolyte to bring up the specific gravity.* Low gravity indicates that a large proportion of the acid is combined with the active material of the plates, and that when the cells are recharged this acid will be returned to the electrolyte; thus any addition will represent an excess.

During the charge the electrolyte gradually becomes stronger, as the sulphate in the plates decreases until no more sulphate remains and all the acid has been returned to the electrolyte, when it will be of the same strength as before the discharge, and the same acid will be ready to be used over again in the next discharge. Since there is no loss of acid, none should ever be added to the electrolyte. The acid absorbed by the plates during the discharge is driven from the plates by the charging current and restored to the electrolyte during the charge. *This is the whole object of charging.*

Charging Rate and Time of Charge. It has been said that every man has a different method of charging a storage battery, but this refers to a variation in the detail of handling the charge rather than the method, as the latter must naturally be the same in all cases, i.e., direct current must be passed through the cells in the right direction. In the use of this current, there are only two factors to be considered, rate in amperes, and time. The rate in amperes is limited by the state of discharge. When the cells are fully discharged, in which condition the plates contain the maximum amount of sulphate, the charging current can be utilized at the highest rate.

Gassing. As the charge progresses and the amount of sulphate in the plates decreases, they can no longer absorb current at the same rate, and the charge must be reduced. This becomes necessary when the cells begin to give off hydrogen gas. This is termed *gassing* and is an important feature of the process of recharging, since *gassing shows at any time whether or not the charging rate is too high.* Passing current through a cell will always be followed by a reaction in the cell; just what this reaction will be depends upon the condition of the cell at the time. In any case the current will always follow the path of least resistance and will accordingly always do the easiest thing first. When the cell is in a discharged state, the easiest thing is to decompose the lead sulphate. As there is a comparatively large amount of lead sulphate in a fully discharged cell, a correspondingly large amount of current can be used in charging. But as the amount of sulphate progressively decreases with the charge, a point is reached at which there is no longer sufficient sulphate remaining to ultilize all the current that is passing through the cell.

The excess current will then begin to do the next easiest thing, which is to decompose the water of the electrolyte and produce gas. Therefore, when the cells begin to gas freely, it indicates that current is being passed through them at too high a rate, and the charge should be reduced sufficiently to stop the gassing. As the charge is continued at the lower rate, the remaining sulphate will continue to decrease in amount until there is no longer sufficient to utilize the smaller amount of current, and the cells will again begin to gas. The charge should be reduced each time the gassing begins. When the cells begin to gas freely at a very low charging rate, it indicates that there is practically no sulphate remaining, so that even this small amount of current cannot be utilized, and the charge is complete.

Discharge. The action of the cell on discharge is briefly as follows: When the cell is connected up to discharge, the current is produced by the acid in the electrolyte combining with the lead of the porous parts of the plates, termed the *active material* which, as already mentioned, consists of lead peroxide in the positive plates and metallic lead in a spongy form in the negative plates. When the sulphuric acid in the electrolyte combines with the lead in the active material, a compound, lead sulphate, is formed. This is formed in the same way that sulphuric acid dropped on the copper wiring, or

terminals, forms copper sulphate, or acid dropped on the iron work of the car forms iron sulphate. In cases of this kind it will always be noted that an amount of sulphate is formed out of all proportion to the quantity of metal eaten away. In the same manner, the sulphuric acid of the electrolyte combines with lead in the plates forming lead sulphate which, on account of its increased volume, fills the pores of the active material.

As the discharge progresses, the electrolyte becomes weaker in proportion to the amount of acid absorbed by the active material of the plates in the formation of lead sulphate, a compound of acid and lead. This lead sulphate continues to increase in quantity and bulk, filling the pores of the plates, and, as these pores are stopped up by the sulphate, the free circulation of the acid through the plates is retarded. Since the acid cannot reach the active material in the plates fast enough to maintain the normal action, the battery becomes less active, as is evidenced by a rapid drop in voltage. Experiences show that at the normal discharge rate, the voltage will begin to drop very rapidly soon after reaching 1.8 volts per cell.

During a normal discharge, the amount of acid used from the electrolyte will cause the gravity to drop 100 to 150 points. Thus, if the gravity of a fully charged cell is 1.275, it will, at the end of the discharge, be between 1.175 and 1.125, depending on the type of cell. The battery should never be allowed to drop below this point, but should immediately be placed on charge.

Efficiency of Storage Cell. About 20 per cent of the energy employed in charging the cell is lost in the process, so that the efficiency of the storage cell in good condition is approximately 80 per cent, this representing the available output of the fully charged cell. By abuse or neglect this percentage of efficiency may fall so low that the figures given will be almost reversed, from which the necessity for properly looking after the battery may be appreciated, particularly when it is expressed in terms of miles per charge and the reduced capacity may mean stranding at quite a distance from a source of current. Fig. 7 shows a typical charge and discharge curve, while Fig. 8 shows the peculiar discharge curve of a cell that has stood fully charged for some time.

From the electrical point of view, the chief desideratum in a cell is high conductivity of its components, as this makes for

efficiency; but for vehicle use, strength, rigidity, and compactness are very essential, and the attempt to reconcile these conflicting requirements is accountable for the varying forms and materials commer-

Hours

Fig. 7. Typical Charge and Discharge Curves

cially employed for the purpose. It is for this reason that the grid form mentioned, into which the material is pasted and then compressed, has been adopted.

Sulphating. The conversion of the active material into lead sulphate, which takes place during the discharge of the cells, is a

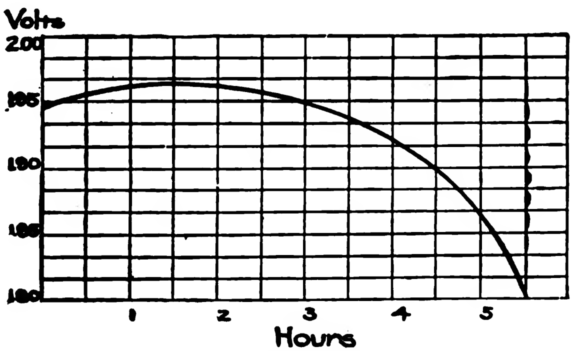

Fig. 8. Peculiar Discharge Curve

normal reaction and as such occasions no damage. If, however, the cells are allowed to stand for any length of time in a discharged condition, the sulphate not only continues to increase in amount but

terminals, forms copper sulphate, or acid dropped on the iron wor of the car forms iron sulphate. In cases of this kind it will alway be noted that an amount of sulphate is formed out of all proportio to the quantity of metal eaten away. In the same manner, the sul phuric acid of the electrolyte combines with lead in the plates forming lead sulphate which, on account of its increased volume, fills the pores of the active material.

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becomes *hard* and white, and the presence of white spots on the plates is an indication that the cells have been neglected. In this condition, the plates have lost their porosity to a considerable extent and it is correspondingly more difficult to force the charging current through the active material. This is the abnormal condition usually referred to as *sulphated.*

Continued and persistent charging at a low rate will restore practically any condition of sulphate, the time necessary being in proportion to the degree to which the condition has been allowed to extend. It is entirely a question of time, since a higher rate will only produce gassing and high temperature, the low rate being all that the cells in this condition are capable of using.

Time Necessary to Restore a Sulphated Battery. The additional length of time necessary to restore a sulphated battery is illustrated by the following test:

Preventing Sulphating. In ordinary charging, there is usually not sufficient time to continue the charge until absolutely all the sulphate has been converted. To prevent the small amount of sulphate remaining from increasing and getting hard, an *equalizing charge* should be given at frequent intervals. Some makers recommend doing this once a week, others every fortnight, and still others once a month. This equalizing charge is an extra long charge at a low rate, whereby no more current than can be absorbed by the amount of sulphate remaining is passed through the cells.

A battery was charged to the maximum, and the gravity regulated to exactly 1.275, with the electrolyte just one-half inch above the tops of the plates, this height being carefully marked. The battery was then discharged and recharged to 1.275 at the normal rate in each case. The specific gravity changed from 1.265 to 1.275 during the last hour and a half of the charge. During the following twelve weeks the battery was charged and discharged daily, each charge being only to 1.265, thus leaving 10 points of acid still in the plate. At the end of the twelve weeks the charge was continued, to determine the time required to regain the 10 points and thus restore the specific gravity to the original 1.275. Eleven hours were needed, as compared with the hour and a half needed at first.

The test further illustrates why it is necessary to give a battery an occasional overcharge, or equalizing charge, to prevent it becoming sulphated. Had the battery in question been charged daily to its maximum of 1.275 and discharged to the same extent during the twelve weeks, nine and a half hours of the last charge would have been saved. It is neither necessary nor desirable, however, to carry every

charge to its absolute maximum. The weekly equalizing charge is better practice.

Restoring a Sulphated Battery. It has become more or less common to suspect the battery of being sulphated every time it fails to give the mileage the user thinks it should give on an electric vehicle, or to have the capacity for starting that, in the driver's estimation, it should have, on a gasoline car. But if the sediment has not been allowed to reach the bottom of the plates, and if the level of the electrolyte over the plates has been properly maintained by replacing evaporation with distilled water, the battery can be sulphated only because it has not been properly charged, or because acid has been added to the electrolyte. An individual cell may become sulphated through an internal short-circuit, or by drying out as might be caused by failure to replace evaporation with water, or failure to properly replace a broken jar.

Sulphate Tests. To determine whether a battery is sulphated when it is known that it does not require cleaning, it is advisable to remove it from the car, give it the ordinary equalizing charge, and discharge it at the normal rate. If it gives its rated capacity, the reason for short mileage should be looked for elsewhere in the electric vehicle, or in the other essentials of the starting and lighting system on a gasoline car. (The removal of the battery refers to an electric vehicle and not to a starting and lighting battery.) If the rated capacity is not obtained on this discharge, recharge in the usual way. When the battery is considered fully charged, take and record a hydrometer reading of each cell and the temperature of one cell. Charge the battery at a rate as near one-half its normal rate as the charging apparatus will permit. If the temperature reaches 110° F., reduce the current or temporarily interrupt the charge not to exceed this temperature.

Treatment for Sulphates. A battery is sulphated only when acid is retained in the plates. When the specific gravity of the electrolyte has reached a maximum, it shows that there is no more sulphate to be acted upon, since during the charge the electrolyte receives acid from no other source. Hydrometer readings should be recorded at intervals sufficiently frequent (four to six hours apart) to determine if the specific gravity is rising or if it has reached its maximum. Continue the charge, recording the readings, until there has been no further rise

in any cell during a period of at least twelve hours. Maintain the level of the electrolyte at a constant height by adding pure water after each reading with the hydrometer. (If water were added just before taking hydrometer readings, the water would not have time to mix properly with the electrolyte.) Hydrometer readings should be corrected for any considerable change in temperature during the charge in accordance with the scale shown in Fig. 9. Should the gravity rise above 1.300 in any cell, draw off its electrolyte down to the top of the plates and put in as much distilled water as possible without overflowing. Continue the charge, and if the gravity again goes above 1.300, it shows that acid has been added during the previous operation of the battery. The electrolyte should then be emptied out, replaced with pure water, and the charge continued. The treatment can only be considered complete when there has been no rise in the gravity of any cell during a period of at least twelve hours of continuous charging.

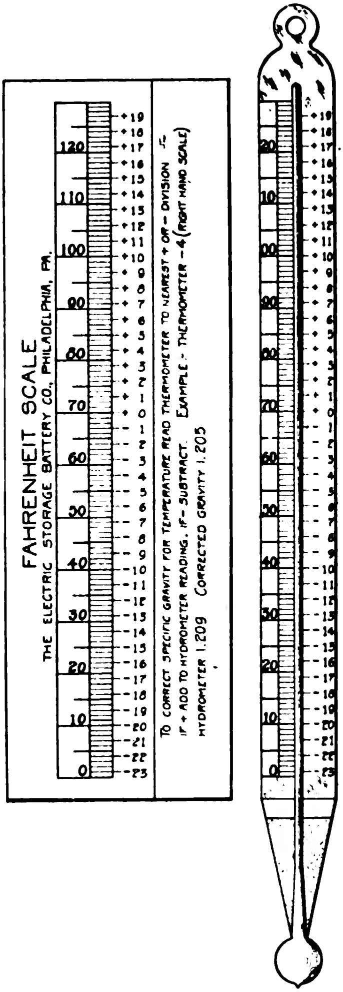

Fig. 9. Fahrenheit Thermometer with Special Temperature Scale for Correcting Density of Electrolyte

Upon completion of the treatment, the specific gravity of the electrolyte should be adjusted to its proper value of 1.270 to 1.280, using distilled water or 1.300 acid as may be necessary. In cases where one or more individual cells have become sulphated, while the balance of the battery is in good condition, it is better to remove such cells and treat them individually. The active material of sulphated negative plates is generally of light color and either hard and dense or granular and gritty, being easily disintegrated. It is the negative plates which require the prolonged

charge necessary to restore a suphated battery. Sulphated positives, unless physically disintegrated or badly buckled, are but little changed in appearance and can be restored to operative condition, although their life will not be as great as if they had not been subjected to this abuse. Sulphated plates of either type should be handled as little as possible. By strictly following the simple rules of operation given in connection with charging and discharging the battery, the expense and trouble inseparable from restoring a sulphated battery may be avoided.

Capacity of Cell. *Depends upon Plate Area.* The ampere-hour capacity of a cell, or the amount of current which it is capable of absorbing and reproducing through the medium of the chemical processes described, is determined by the area of its plates. This area

Fig. 10. Complete Battery of Cells for Pleasure Car

depends upon the area of the single plate as well as upon the number of plates the cell contains. It is customary to make both outside plates in a cell negatives, so that the cell contains an odd number of plates and its capacity is fixed by the number of positives. The ampere-hour capacity of a battery, the cells of which are all connected in one series, is the same as that of a single cell in the series; just as, in connecting up dry cells or other primary batteries in series, the current output is always that of a single cell, while the voltage of the current increases with the number of cells thus connected.

Its capacity, in turn, limits the safe rate at which its output may be discharged. This area may be large or small, but, as high capacity and discharge rate are desirable, and as the battery space in a vehicle is limited, the makers must use the greatest possible plate area within

limits of good mechanical construction that may be employed in a container of given dimensions.

Depends upon Amount of Active Material. The ampere-hour capacity of a plate depends upon the amount of available active material it contains. Since acid and lead combine with each other in a definite proportion in producing current, it might seem possible to have acid and lead in a cell in such quantities that both would be completely exhausted. Toward the end of the discharge, however, the electrolyte would be so weak that it would not be capable of producing current at a sufficient rate for any practical purpose. For this reason it is necessary to have acid in the electrolyte in excess of the amount actually used in the plates during discharge. Similarly, if all the active material were combined with acid, the plates would lose their porosity and conductivity, and an excess of lead active material would be provided.

A complete assemblage of cells for a pleasure car is shown in Fig. 10.

CONSTRUCTION AND EFFICIENCY OF CELL PLATES

Thick vs. Thin Plates. The idea that a thick plate would give longer battery life than a thin one was one of the numerous causes of the low efficiency of the early electric vehicles. The weight was greatly increased and the capacity of the cell reduced in the same proportion, and it was only with a considerable reduction in the thickness of the plates with a correspondingly greater number per cell that practical mileages were reached. The dimensions adopted have been adhered to for a number of years and have become recognized as standard. However, in the past few years a thin-plate type of battery has been developed very successfully. A belief still prevails to some extent, however, that the life of the standard cells is longer, since it will naturally take longer for the thicker layer of active material to slough away from its supporting grid. But storage-battery capacity is dependent, among other things, upon the surface of the active material presented to the electrolyte. Conversely, the rapidity with which this material wears away depends upon the density of the current drawn from it. Considering the 35-ampere-hour capacity, 4-hour discharge-rate cell composed of 11 thick plates, there is a discharge of 7 amperes per positive plate. If, as is now frequently

done, 15 plates are employed in the same size of jar, the discharge per positive plate is only 5 amperes. Therefore, if there is more material to slough away in the thick plates, there is, on the other hand, but five-sevenths of the sloughing effect on the thin ones. But there is a still more important consideration. The active material lying between the two plate surfaces is not of the same value as the surfaces themselves, because of mechanical, as well as of electrical, reasons. Once the surfaces disintegrate, the bulk of material behind them falls away more rapidly and gives poorer efficiency.

Another advantage of thin plates is the reduced heating effect due to high discharge rates on hills or poor roads, such discharges being handled better by improved acid diffusion and the larger percentage of conducting grid to active material. If vehicles operated continuously at full speed without grades or stops, this would have little bearing on the question; but as one of the chief functions of the electric is its easy and frequent starting ability, it is evident that the high currents necessary for this purpose are handled to better advantage by many thin plates than by a few thick ones.

Measurement of Capacity. The standard unit for measuring capacity of a storage cell is the ampere hour, which means a current of one ampere flowing for a period of one hour. When the capacity of a cell is stated as a certain number of ampere hours, this indicates that the cell will deliver 1 ampere of current for the period given, 2 amperes for one-half that period, etc. This does not mean, however, that this progression may be carried to the other limit, as the efficiency of the cell falls away as the discharge rate becomes greater. In other words, while a 100-ampere-hour cell will produce 1 ampere for 100 hours, 2 amperes for 50 hours, 4 amperes for 25 hours, and so on in the same proportion, it will be found, as the rate of discharge increases, that the capacity will fall off, the same cell not being able to deliver 25 amperes for four hours, or 50 amperes for two hours.

In former years, the capacities of all lead-plate cells for vehicle use were based on a four-hour rate of discharge. Thus a 140-ampere-hour cell was guaranteed to discharge 35 amperes for four hours. Since the introduction and more or less general use of thinner plates, many makes are sold on a basis of a 5-, 5½-, and even a 6-hour rate, so that 35 and even 37 or 38 amperes are guaranteed for five hours or more from a battery occupying no greater space.

Rate of Discharge. Since the current is produced by the action of sulphuric acid combining with lead in the plates, the rate at which the acid can penetrate the active material determines the maximum rate at which current can be produced. For instance, if the same amount of material used in making a nine-plate cell were employed in but two plates, one positive and one negative, the ampere-hour capacity at a sufficiently low discharge rate would be just the same as if this material were divided into four positives and five negatives. At ordinary rates of discharge, however, the acid could not penetrate the active material of such a thick plate fast enough to maintain the discharge rate for the required time. If these same plates were split into thinner plates, the acid could much more readily get to that portion of the material which in the thick plates was farther removed from the surface, and current could therefore be produced more rapidly. It is, consequently, apparent that the material can be divided into thinner and thinner plates to maintain an increased rate of discharge. But the thinner the plates, the shorter the life of the cell under ordinary conditions of service, as has been explained just previously.

Safe Discharge Point for Plates. The point to which the cell can be safely discharged is not limited by the period during which it is used so much as by the voltage of the cell itself. The discharge should never be carried so far that the voltage falls below 1.8 volts per cell, while the voltage when charged should be 2.2 volts per cell, or slightly in excess of this, especially just after the completion of the charge. The majority of vehicle batteries are designed to have a normal eight-hour rate of discharge, and their capacity, for pleasure cars, seldom exceeds 180 ampere hours. Such cells will discharge 10 amperes for a period of 10 hours without falling below 1.8 volts, provided conditions of charging and discharging have been favorable, and the battery is otherwise in good condition. During the discharge the sulphuric acid, as indicated by the chemical equation already given, is partially converted into water and lead sulphate, and when carried to extremes, the electrolyte would be practically all water, and the voltage would fall to about 1.46, virtually ruining the cells. However, the sulphion, or SO_3, is only abstracted from the electrolyte where it is in contact with the plates. As it is removed, the density of the fluid decreases, and a circulation

is set up, thus permitting fresh acid to take the place of that exhausted. The chemical action is naturally most rapid in the minute pores of the plates where circulation is most difficult, so that when the cell is allowed to stand idle, the fresh electrolyte penetrates the plates and there is a correspondingly marked rise in the voltage of the cell. This explains what is known as the *recuperative power* of the storage cell, in which the voltage will rise very soon after breaking the circuit, even in a cell that has been almost entirely discharged.

Theoretically, we should be able to take from the storage cell the same amount of electricity as is put into it, but this is not the

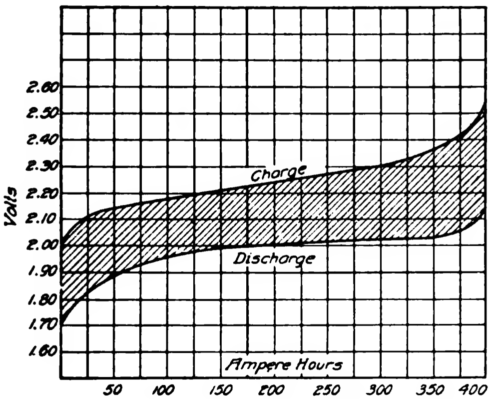

Fig. 11. Relation between State of Charge and E.M.F. in Lead Storage Cell

case. The cell absorbs an amount of electric energy, as represented by the following equation:

$$W = E \times Q$$

in which W equals the energy expressed in watt hours, E is the terminal e.m.f., or potential, in volts impressed upon the battery, and Q is the quantity of electricity in ampere hours absorbed by the battery. The loss of energy incidental to the operation of the battery is manifested in the reduction of the terminal e.m.f. on discharge, or the difference between the potential required to charge it and that at which it discharges. Characteristic curves of a lead cell showing the voltage on charge and discharge and the relation the voltage bears to the state of charge is given in Fig. 11. The loss of energy due to the drop in voltage is represented by the cross-

hatched area between the two curves and shows how much more current must be put into the cell than can be taken out of it.

Life of the Cell. In view of the extremely severe nature of the service it is to be employed for, when designed for electric vehicle use, it will be evident that there are numerous requirements that must be met by the successful storage cell made for this purpose. The chief difficulty is to be found in the fact that the conditions under which the cell must work are directly opposed to the successful maintenance of its most necessary features. For instance, to be efficient, the plates must be as porous as possible, in order to permit of a free circulation of the electrolyte through the active material. On the other hand, they must be made as durable as a board, in order to withstand the effects of jolting and vibration. The arrangement of the grid and the active material should be such that the current may flow equally through all parts of the completed electrode. This requires that the electrical resistance from any two points in the plate should be the same to the connecting lug, something that is naturally impossible of achievement and is only approximated as closely as conditions will permit.

Provisions for Expansion and Contraction of Plates. The construction of the grid must be such as to allow of its expansion and subsequent contraction under the heat of charging and discharging, without the expulsion of the active material from the containing pockets, and without causing it to crack and fall to the bottom of the cell. This is doubtless the most prolific single source of storage-battery troubles, and the fact that it is one of the most difficult requirements to be met in the manufacture of the cell is responsible for the maker's injunction never to charge at such a rate that the temperature will be greater than 110° F., cells in the center of a group being taken as a guide. Unceasing investigation and experiment extending over many years have been devoted to an attempt to solve this problem without finding an adequate remedy, as the expansion during the process of formation, or charging, as it is generally called, is very great. In the Edison cell, in which an alkaline solution is employed in connection with iron and nickel electrodes, the active material is placed in small steel tubes and pockets under great pressure, and the latter are then similarly fastened in the grids.

The method of fastening the active material in the grids is really the crux of the problem, as it must not alone be mechanically sound, but must also make good electrical connection, if the battery is to be efficient. Expansion causes the active material to loosen and become separated from its metal foundation, and as this progresses, the electrical contact becomes poorer and the efficiency of the cell decreases. The ultimate loss of contact places the cell out of commission. There are further requirements in addition to those men-

Fig. 12. Bijur High-Duty Battery Plate

tioned, such as the necessity of making the grid proof against corrosion. This is likewise a practical impossibility, but has been overcome to the extent of using material so proportioned that both grid and active material will have an equal life and may be replaced together. Local action, by which is meant the formation of an electrical couple through differences in the material of the grid and the active material, thus constituting a cell, or many of them, within a cell, must likewise be avoided. Quite as important as any of the

foregoing is the provision for circulation, and the active material must be so disposed as to present the greatest possible amount of surface.

Some typical forms of grids illustrating the manner in which these various conditions have been met by a number of different manufacturers are shown in Fig. 1, Fig. 4, Fig. 5, and Fig. 12. A section of a complete cell, Fig. 13, shows how its components are assembled.

Use of Separators between Plates. In a storage cell for stationary service the plates are separated merely by allowing a certain

Strap

Strap

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or

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Fig. 13. Part Section of Exide Storage Cell Showing Complete Assembly
Courtesy of Electric Storage Battery Company, Philadelphia

space between them, but this would obviously be out of the question in a vehicle battery. An insulating separator is accordingly quite as important a component of the cells as the electrodes. Very thin sheets of corrugated wood are generally employed, with thin sheets of perforated hard rubber placed on each side of them. These insulating unit groups exactly fill the space between adjacent plates so as to permit of no relative movement whatever. No matter how well the cell is made, or of what type, where lead grids are employed, disintegration of the active material is constantly going on in service and as this material is an excellent conductor it must not be permitted to come in contact with the plates. The latter are accordingly placed

on strips of wood to raise them from the floor of the cell and to permit the loosened active material, or sediment, to fall clear of them. Hard-rubber ribs, integral with the jar, are also used.

Containers for the Cell. The remaining components necessary to complete the cell consist of a suitable container for the electrolyte and electrodes, a means of closure, provision for the escape of the gas generated during the process of charging, and means for connecting the cell electrically to its neighbors on either side that go to compose the battery. The containing jars are usually made of hard rubber and have covers of similar material which are sealed in place with a compound specially made for the purpose and which melts at a comparatively low temperature. The connecting lugs project through these covers and are usually burned to straps or bars of lead. The cover is also provided with a vent for the escape of gas, this opening usually being closed with a soft-rubber plug, intended to be taken out when the battery is on charge. Groups of cells. usually in fours or multiples thereof, are held in oak cases.

TYPES OF CELLS

General Characteristics. It will be noted that there is considerable difference in the appearance of the various plates illustrated here, and it may be added that there is a corresponding difference in their construction. Despite the almost innumerable attempts that have been made to discover materials that would not have the disadvantages of bulk and weight for storage-battery work, the lead-sulphuric-acid type is still commercially supreme. Although there are many minor variations of design and construction, there are two general classes of lead plates employed. These are the Planté and the Faure. In both, lead peroxide is the active material at the positive electrode and finely divided spongy metallic lead at the negative, one of the means of distinguishing the plates apart being their color, the negative showing a dull gray, while the positive is red. The plates of the Planté type consist of pure lead of relatively small sectional area, with all exposed surfaces scored, fluted, or corrugated in similar manner to increase the area that can be reached by the electrolyte.

Pure lead is very soft and yielding, and it is often necessary to supply a supporting framework of hard cast lead to lend additional

stiffness to the plates, particularly for vehicle work. These plates and the electrolyte complete the Planté type of cell, as the active material is directly formed electrochemically from the material of the plates themselves by being subjected to a series of charges and discharges. In the Faure type, a cast grid of comparatively hard lead is employed as the foundation, and the active material is placed in the interstices in the form of a stiff paste, the whole plate being subsequently subjected to considerable pressure. On this account it is usually referred to as a pasted type of plate. The Exide cell, plates of which have been illustrated in Figs. 4 and 5, is representative of this class.

Only the Faure type is used for vehicle batteries as the Planté is a "formed" plate from which the active material would be shaken by the vibration.

Improved Forms

Nature of Improvements. The foregoing are what are known as *flat-plate* types of elements, and the life of this form of battery is usually measured in terms of the life of the positive plate, as it is the latter which suffers most from the charging and discharging process. It is nothing unusual for the other elements in the cell combination to outlast the positive plate two or three times over, new separators being installed with each renewal. Accordingly, the problem has been to devise a type of positive plate that would equal the negative in durability. Many forms of protective coverings designed to prevent the active material from washing out of the plate have been tried with varying degrees of success. Among these have been plates built up of parallel cylindrical pencils of the active material. While the latter did not prove a solution of the problem in its simple form, this idea, in combination with a basic principle originated by a French maker, served as the foundation for what is known as the "Ironclad" Exide type. For this form, the makers claim that the positive plate not only lasts practically as long as the negative, but that the battery is capable of withstanding the abuse of overcharging to a degree never before attained. The importance of the latter in the commercial use of electric vehicles can hardly be overestimated and is brought out in the paragraphs on "Boosting", Part II.

Ironclad Exide Type. *Positive Plate.* The Ironclad Exide positive plate consists of a grid composed of a number of parallel vertical metal rods united integrally to horizontal top and bottom frames, the former being provided with the usual conducting lug for carrying the current. Each vertical rod forms a core, which is surrounded by a cylindrical pencil of peroxide of lead, which is the active material. These pencils are enclosed in hard-rubber tubes having a large number of horizontal slits, which serve to provide access for the electrolyte, or solution, to the active material, but are of such small dimensions as to practically eliminate the washing out of the material. Fig. 14, which shows a vertical section of one of these composite pencils, makes this construction clear. The outside tubes are reinforced by leaving the exposed edge solid, i.e., without slits. Each tube is provided with two parallel vertical ribs projecting on opposite sides at right angles to the face of the plate. These ribs not only serve to stiffen the tubes, but, being of hard rubber as are the tubes themselves, also act as insulating spacers, allowing the use of a flat piece of wood veneer in place of the ribs on the wood separators in other types.

Fig. 14. Vertical Section of Positive Plate Pencil

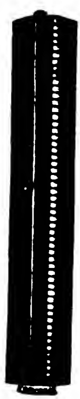

Fig. 15. Positive Pencil Showing Rib

Fig. 16. Assembled Exide Positive Plate

The reinforcing rib is shown by Fig. 15, which is a side view of the tube. These rubber tubes have a certain amount of elasticity allowing them to compensate for changes in volume of the active material, owing to the expansion and contraction during charge and discharge. A complete positive plate of this type is illustrated by Fig. 16. This cylindrical form of tube is peculiarly well adapted to perform its function, since no amount of expansion or contraction will tend to alter its shape, and the internal stresses are thus kept uniform. Another advantage is that most of the electrolyte necessary is carried within the confines of the plate itself. This is illustrated by a comparison of horizontal sections of portions of the Ironclad Exide plate and the standard Exide plate, as shown in Fig. 17.

Negative Plate. To conform to the construction of the new positive, the negative is also modified somewhat, the upper and

Exide

Fig. 17. Comparative Sections of "Ironclad" and Standard Exide Plates

lower edges of the plates being encased in rubber vulcanized in the plate. This eliminates the possibility of short-circuits from material bridging across from the positive frames. The negative frames are undercut, so that the rubber sheathing is flush and does not project beyond the face of the plate. The thickness of this negative plate is calculated to provide approximately the same life as the positive, thus avoiding partial renewals, which cut down the efficiency of the cell.

Separators. The special form of the positive plates renders unnecessary the flat perforated rubber sheet used in the standard types of cells, the only separator employed being the wood veneer mentioned. The greatly increased life of the new cell made it necessary to employ a separator of greater durability than those in current use and, after investigation, a special kind of wood possessing great toughness, as well as ability to resist the action of the electrolyte to

a remarkable degree, was adopted. These separators are made with the grain of the wood running horizontally in order not to register with the vertical ribs on the positive plates, which would tend to split the wood. The positive and negative plates are

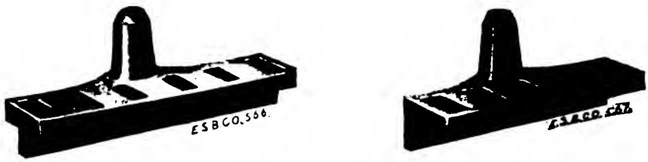

Fig. 18. Pillar Type of Strap Connectors
Courtesy of Electric Storage Battery Company, Philadelphia

grouped in the customary manner, the lugs being burned directly to the usual lead straps, except that the straps are of the pillar type, illustrated by Fig. 18.

Improved Connectors. Mention has been previously made of the necessity of providing the maximum conductivity in the elements of the cell as well as in the units of the battery in order to keep its internal resistance down, as upon the latter depends its ability to discharge its energy at a high rate, this being a valuable characteristic for hill climbing or bad road conditions. The usual practice has been to employ the same alloy of lead and antimony for connecting the cells, the latter having strips of the metal burned to the pillars or other projections designed for receiving the inter-cell connections. For this purpose, the makers of the Ironclad Exide cells have brought out an improved form of connector, shown in Fig. 19. This is known as a built-up type, consisting of thin strips of copper, lead-covered to prevent corrosion. A number of these strips, depending upon the current to be carried, are laid face to face, and their ends cast into lead-alloy terminals, a special welding process insuring effective and permanent contact between the flexible strips and the cast terminal. By this means, good conductivity is obtained under all conditions of vibration and temperature changes. The lead-alloy terminals are ring shaped to fit over the pillar of the strap and are burned in place. The use of copper gives a higher conductivity than lead alloy, while the laminated structure provides a flexible, instead of a rigid, connection.

Fig. 19. Lead-Covered Copper Connecting Strip
Courtesy of Electric Storage Battery Company

Starting Batteries. The advent of electric starting motors on the automobile has been responsible for adding to the problems of the storage-battery maker. As outlined in the chapters devoted to starting and lighting, the requirements are such that the maximum output of which the battery is capable is called for instantaneously

Fig. 20. Sectional View of Titan Cell Showing Diagonal Ribs of Active Material to Lessen Resistance
Courtesy of Horseless Age

every time the gasoline motor is started. Any one who has cranked a car on a very cold morning after the motor has been idle over night will realize the greatly increased effort necessary to move the pistons, owing to the adhesion caused by gummed, or partly frozen, lubricating oil. Special provision is accordingly necessary to reduce the internal resistance of the cells of the battery in order that it may deliver its maximum output, the demand usually representing a considerable

overload. One method of attaining this is shown in the "Titan" cell, in the positive plates of which the conductivity afforded by the grid is greatly increased by the provision of diagonal ribs running in the general direction of the points where connection is made to the strap, as illustrated by Fig. 20, which shows a section of the cell. This increased conductivity tends to reduce the tendency of the plate to buckle and force out its active material when subjected to such a heavy demand for current.

In addition to the service being of such a severe nature, the conditions under which a starting battery must operate are equally strenuous in other respects. Touring cars are driven at very much higher speeds than electric cars and frequently over rough roads, which greatly adds to the amount of vibration that the plates must endure. Special provision must accordingly be made for the reception of a greater amount of sediment and in a manner which will prevent the latter from reaching the bottom of the plates. This takes the form of an increased depth of electrolyte below the elements, while the space thus allowed is provided with an increased number of baffle plates, or partitions, to prevent the sediment from being washed about and accumulating in one place. The Titan cell is an illustration of this, and it is also shown in the Gould cell, Fig. 21, which also incorporates the use of built-up connectors of copper and lead. Both of these cells likewise embody an improved form of cover. They are enclosed by two hard-rubber covers and an intermediate layer of sealing compound in adhesive contact with the sides of the jar. Sleeves of hard rubber permit of some flexibility at the pillars while still insuring an air-tight joint with the sealing compound.

Fig. 21. Gould Starting Battery Cell Showing High Mud Space

Integral with the lower cover is an expansion chamber communicating with the interior of the cell and provided with a threaded cap. In the case of the Gould cell, leakage is guarded against by the inverted conical form of this cap, and as the battery boxes are now made in accordance with the S. A. E. standard dimensions, they may

be placed end to end, reducing the thickness to $4\frac{1}{2}$ inches in the largest size, and permitting the battery to be suspended between the chassis frame and the running board, concealed by an apron.

Edison Battery. Inasmuch as the Edison battery represents the only successful attempt to make use of a reaction other than that of the lead-sulphuric-acid couple discovered by Planté, the inventor of the so-called storage battery, the Edison cell is of unusual interest. Placing this battery on the market in commercial form is said to have involved the expenditure of more than two million dollars, as special processes and costly machinery had to be originated for its manufacture, while more than fifty thousand separate experiments were made in a period of seven years before the solution of the problem itself reached the stage where manufacturing could be undertaken.

The elements of the Edison cell consist of nickel and iron in an alkaline solution, and, as the capacity of a storage cell depends upon the area of the active material in contact with the electrolyte and upon the conductivity of its members, the problem was to utilize these materials in the form best adapted to give efficiency and durability. Three years were devoted to this phase of the problem, after the reaction giving promise of success had been discovered, before the first crude cell was made.

Composition of Plates. The positive plate of the Edison cell consists of vertical rows of thin, perforated steel tubes filled with nickel hydrate, these tubes being supported in a steel frame somewhat similar in appearance to a pencil-form lead grid, as will be noted by reference to Fig. 22, which shows a positive and a negative plate complete. Rows of flat, perforated steel jackets filled with iron oxide, likewise held in a thin steel frame, compose the negative plate. The elements are, accordingly, nickel, iron, and steel in a 21 per cent solution of potash in distilled water, and these elements constitute a storage cell which differs radically in every respect from the lead-plate type. In fact, this is the only storage cell the elements of which are not attacked by the electrolyte when left standing in a charged, partly-charged, or wholly-discharged condition for any length of time. Apparently the potash acts as a preservative of all the elements entering into the combination.

Iron oxide will be recognized as one of man's most persistent and ubiquitous enemies, rust. Nickel hydrate is the product of a

special electrolytic process originated by Mr. Edison. When on charge, this iron oxide, or rust, of the cell's negative plate is converted into metallic iron, while the oxygen generated passes over to the positive plate and converts the nickel-hydrate content into a new form of nickel oxide, previously unknown to science. The oxidizing of the nickel hydrate causes it to expand just as the peroxide

Fig. 22. Assembled Positive and Negative Edison Plates

Fig. 23. Completely Assembled Edison Cell

of lead of the lead positive plate does, but there is no danger of loosening or loss of the active material in this case, as it is held in a rigid steel tube. The latter has numerous fine perforations to permit access of the electrolyte, but these are so numerous that the steel approximates wire netting or gauze.

The container is of steel welded in a special machine making it an integral unit which cannot be opened without destroying it.

Protruding through the top and surrounded by hard-rubber washers are the two tapering terminals, and between them is the filler cap through which the solution of potash and distilled water is introduced. This cap acts as an automatic relief valve which allows the gas generated to escape but prevents the entrance of air. The cells are connected by nickel-plated solid copper strips fastened to the threaded terminals with nuts so that the units of a battery may be taken apart readily, Fig. 23. The cells are fitted in wooden trays and tightly clamped in place, Fig. 24.

Advantages and Disadvantages. Chief among the advantages of the Edison battery for commercial-vehicle use are its long life and

Fig. 24. Tray of Four A-4 Edison Cells

its ability to withstand what would be considered flagrant abuse, if applied to a lead battery. It may be charged or discharged at any rate within the current-carrying capacity of its connections, allowed to stand either charged or wholly discharged for any length of time, without injury, and in other ways subjected to electrical abuse which would ruin a lead-plate battery in a comparatively short time. As evidence of its durability and continued electrical efficiency even under such treatment, it is guaranteed for four years' use.

While the voltage of each cell is but 1.25 volts as compared with 2 volts for the lead cell, its construction is so much lighter that there is a saving in weight in battery of Edison cells when compared with a

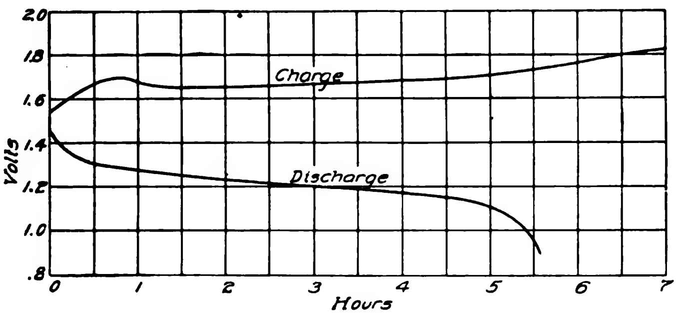

Fig. 25. Charge and Discharge Curves for Edison Cell

lead battery of the same voltage and capacity, despite the added number of the former necessary to give the same potential. Fig. 25 illustrates the charge and discharge curve.

Size of Battery. The voltage of the vehicle circuit has a twofold bearing upon the latter's efficiency. On one hand, there is the factor of efficient utilization of the energy and, on the other, of the charging efficiency of the battery. Thus there is a constant loss at both ends which accounts for the abandonment of 24- and 30-volt batteries which were common in electric cars of the pleasure type about 1905. The most common voltage of direct-current lighting and power circuits is 110. To charge less than 42 or 44 lead cells or 60 alkaline cells means a loss of current in the rheostat, this loss increasing as the number of cells decreases. This makes the vehicle owner pay for many more kilowatt hours than he receives in the form of energy in the battery. With a 30-cell lead battery, for example, charging on 110 volts, one-third of the current paid for by the user is wasted, so that it is now customary to employ 42- or 44-cell batteries on most of the heavy-type commercial vehicles, though practice in this respect varies on pleasure cars according to their weight, the range usually being from 30 to 42 cells, the former number being used for light three-passenger vehicles and the 40- and 42-cell batteries in broughams and limousines. With alternating currents this objection does not hold good.

THE MOTOR

Quite in contrast with that of the gasoline car, the motor of an electric vehicle is probably responsible for less of the troubles encountered than any other one of the essential components. While the relative amount of attention it requires at the hands of the owner of the vehicle is small, a knowledge of its construction and working will be found of value in the operation and maintenance of the car. It is here that the energy held in reserve in the storage battery is converted into the mechanical power necessary to move the vehicle. The reason for the small amount of attention required is apparent in the small number of parts as well as their great simplicity, though the great amount of attention that has been devoted to the development of the electric motor over a long period of years is largely responsible for the elimination of the numerous shortcomings of the earlier types.

Essentials of Motor. The motor consists of a *field*, an *armature* suitably mounted on bearings so that it may be revolved in that field, a *frame*, a *commutator*, and *brushes*. The term *field* is the generally accepted abbreviation for magnetic field, which is the zone of influence exerted by a magnet, and is referred to in terms of its "lines of force". A common horseshoe magnet, technically known as a *permanent magnet*, will attract to its ends or poles particles of iron and steel placed within a certain distance of it. The space bounded by the poles of the magnet and the limits to which its attraction reaches, is known as its *field*. With reference to electric motors and generators, the word is employed to designate the magnets and pole pieces which serve to create this field, rather than the scope of magnetic attraction itself, and it is used to embrace all of them, regardless of their number.

Principle of Rotation. The fundamental principle upon which the functioning of all apparatus of this type is based is to be found in the fact that when a current of electricity is passed through a coil of wire surrounding a bar or other form of iron or steel, the metal becomes magnetic in proportion to the number of turns in the coil of wire and the strength of the current employed. Every magnet consists of a north and a south pole, and *like poles repel while unlike poles attract one another*. In other words, if two small common mag-

nets are placed on a table with their like poles, i.e., north to north and south to south, facing one another, the magnets as a whole will tend to repel one another, and were they sufficiently powerful, would actually recede from the common center until the limits of their field were reached. By reversing the polarity of the opposing ends of the magnets, they would then tend to be drawn to one another until the poles butted. This, in brief, sums up the philosophy of the electric motor.

In order to amplify the power, a large number of magnets are employed; and in order that the energy thus developed may be utilized, one group of magnets is made stationary while the other group is free to revolve. In these two groups will be recognized respectively the field and the armature of the motor, and each magnet of the groups is of the type known as *electromagnets*, so termed because they are magnetic only while a current is passing through their exciting coils. Those of the field may be distinguished as they take the form of short thick spokes radiating from the rim or frame toward the center. They thus surround the space in which the armature revolves, and are further provided with what are known as *pole pieces* in order to fill as much of the space with iron as is possible. As already mentioned, the field of a magnet is most powerful in close proximity to it and the armature will be seen to run as closely to the faces of the pole pieces as good design and construction will permit.

Now it will be remembered that the direction in which the current of electricity is sent through the exciting coil determines the polarity of the resulting magnet. If, with the current traveling round the coil in one direction, the right-hand end of a bar becomes of north polarity and the left-hand end of south polarity, it will be evident that, by reversing the direction of current flow, there will be a corresponding change in the location of the poles. Coming back to practice, in which one set of magnets—the field—is held stationary, while the other may revolve, it will be apparent that as each of the armature magnets approaches a field magnet by virtue of the attraction between them, the motion will tend to accelerate up to the point where they are opposite, but when the moving magnet passes by, the attraction which still exists will tend to stop the rotation. It is clear, therefore, that, to bring about the desired rotation of the armature some device must be used to reverse the direction of the current

in each electromagnet when it has reached a point opposite the field magnet which is attracting it so that the resulting *opposite polarity* may develop a repulsion which will carry the armature in the same direction. This is just where the function of the commutator and the brushes comes in. The brushes serve to lead the current to the circular group of copper bars which forms the commutator, without retarding the rotation of the armature. Each section of the commutator is insulated from its neighbors and as the brushes touch opposite sections simultaneously the rotation makes the current enter the armature coils first in one and then in the opposite direction, through successive sections of the commutator, the current being reversed and the polarity of the field magnets being changed for each new position.

The Armature. The foundation of the armature consists of a cylinder built up of laminations of iron, or punchings, with recesses cut into their circumferences to receive the coils of wire, or windings, each one of which converts the particular section of the core that it surrounds into a powerful electromagnet when the current is passing. All the wire employed is strongly insulated, not only to protect neighboring turns from one another, but each winding is also well insulated from its foundation, whether this be the armature or a field core. If this precaution were not taken, *short circuits* or *grounds* would occur. The former term is really self-defining as it shows that the current instead of passing round the entire coil or circuit intended, would choose the shorter path thus accidentally provided. A ground, on the other hand, is caused where non-insulated portions of two different wires carrying a current come in contact with the same or a connecting piece of metal, or other conducting medium. This opens up a path of practically zero resistance for the current, thus diverting it entirely from the path it should follow if its energy were to be utilized.

Both short circuits and grounds are things with which the owner of the electric vehicle will have to become familiar to a greater or less extent in caring for the battery of his car, as well as the remainder of its electrical equipment, so that their nature has been explained in detail. While both cause similar results, they are not interchangeable terms and are employed to convey the distinction mentioned. In other words, a ground may be a short circuit, but a short circuit

is not always a ground, as the latter implies the diversion of the current through some normally unused conducting medium, while the short-circuit signifies a breakdown of the insulation of the wiring or allied appurtenances that permits of the return of the current after having traversed but a fraction of the path intended for it. Either trouble naturally places the piece of apparatus in which the break occurs out of running order until the defect is remedied. In view of their nature, grounds are usually much more difficult to locate than short-circuits. Some of their further causes and results are mentioned in the chapter devoted to the care of the batteries, also that on the wiring.

Capacity for Overloads. It is this capacity of the motor to stand excessive overloads that fits in with the requirements of the road, for it must be borne in mind that the amount of power required to keep a vehicle rolling after it is once started is very small as compared with the pull necessary to start it, or to accelerate its speed. The total amount of energy required is in direct proportion to the total weight, and to the square of the velocity.

Motor Stands 500 Per Cent Overload. The pull, or *torque* of the motor as it is called, must be very heavy at starting, particularly when on an upgrade, and also for mounting inclines. For this reason, the motor employed is of a type capable of standing for short periods as much as 500 per cent in excess of its normal rated capacity. It will be apparent that this converts the 2½-horsepower motor into one of 12½ horsepower in cases of emergency, without increasing its current consumption under the ordinary conditions of load at which the greater part of its service is rendered, such as in running on the level or ascending ordinary inclines. The available amount of power being so closely restricted by the capacity of the battery, it will be manifest that this is a most important provision, and as the average layman talks in terms of horsepower without adequately comprehending the meaning of the latter, electric vehicle makers have found it expedient to omit any mention of this factor. The electric not only is not intended to be capable of the speeds of the gasoline car, but it does not require such an excessive amount of reserve power as it has become customary for the manufacturer to provide on the latter type.

Under usual conditions of running, the average gasoline machine

does not employ more than a small fraction of the available power of its motor and, in consequence, is seldom being operated at what is technically termed its *critical speed*, that is, the speed at which it is most efficient, and therefore most economical. In the case of the majority of gasoline cars, this critical speed is from 25 to 30 miles an hour, or even higher, while for the average electric car it is from 10 to 15 miles an hour, a speed which corresponds so nearly with the usual speed on the road that the economy of the electric is very great.

Parts of Motor. The foregoing description of the electric motor for automobile use will be clear upon reference to Fig. 26,

Fig. 26. Parts of Typical Electric Vehicle Motor

which represents a largely used standard type. In the foreground is shown the armature, at the left hand of which is shown the commutator. The coils of wire on the armature run parallel to its length, but in order to save them from injury they are protected by a covering and this is in turn held on by the circular bands shown, which prevent any tendency of the heavy coils to fly out of their slots owing to the effect of centrifugal force. At the commutator end of the armature will be seen one of the annular ball bearings upon which it runs. This is the most advanced type of anti-friction bearing extant, and while its first cost is correspondingly high, its use is justified by the great power saving accomplishment as well as the extremely small need for attention that it involves. These bearings consist of two parallel races and a number of very accurately dimensioned balls distributed at equal distances around the circle by means of a

bronze spacer. Only the very finest materials and the most accurate workmanship are permissible in successful bearings of this type. They are generally employed in electric vehicles, and a further reference is made to them in connection with transmission design.

Directly back of the armature is seen the frame, and from the description, the field coils and the pole pieces will be readily recognizable. The great amount of attention that has been devoted to making the motor as compact as possible will be evident from the mounting of its accessories. It will be seen that the housings are designed to carry both the bearings and the brushes, the latter being attached to the inner face of the cover plate shown at the right. The parts shown in the illustration comprise the motor complete, even including the cap screws necessary to assemble it.

Motor Speeds. *Types of Motor Windings.* The speed of electric vehicles is a most elusive quantity to the uninitiated, principally because the characteristics of the series-wound motor employed are not commonly understood by the layman. The series type of motor is one in which the windings of the armature and field are connected in series, i. e., so that the entire current fed to the motor passes through both of its elements consecutively, so to speak. In a shunt-wound motor the field is in multiple with the armature, so that, while the entire current passes through the latter, the amount taken by the field is always proportioned to that required by the armature for the load it happens to be carrying. As this type of motor is designed for a constant speed, it is not an economical motor to use on the electric vehicle owing to the wide fluctuation of both speed and load imposed, so that its employment is comparatively rare in this field. A compound-wound motor is one having both series and shunt-coil windings on the fields. Since most commercial motors for driving machinery, elevators, and the like are of the constant-speed, compound-wound type, there is a general impression that the electric car should have a certain nearly constant speed for all road conditions.

Advantages of Series-Wound Motor. But in the series-wound motor, the speed varies inversely as the power produced. In other words, its torque, or pulling power, is highest at low speeds, which is just the requirement demanded in starting or pulling through heavy roads. This type cannot be employed for ordinary com-

mercial use, since it will instantly "run away" or race upon the load being released, but it can be employed to advantage on vehicles and in railway service because it is never disconnected from the load. "Load" in this case refers to the effort required to move the vehicles rather than the live load. Series motors are employed on the electric car because of their higher efficiency, which is of prime importance, since the object is to produce the greatest amount of useful energy from a given and limited amount of potential energy stored in the battery. Just the opposite of the gasoline engine, the chief characteristic of the series-type electric motor is the development of increased power with a decrease in the speed. Therefore, as the vehicle requires greater power for bad roads or grades, it slows down automatically and in a fixed relation to the power demanded.

High-Speed Single Motor Present Practice. Opinion and practice are divided on the subject of motor speeds. The higher-speed motors are more efficient, are better for grades and starting, but mechanical limitations frequently make them undesirable. Where formerly motor speeds ranged from 650 to 1100 r.p.m., modern practice favors higher r.p.m. rates, ranging from 1000 to 2000. Normal speeds under 1000 are not satisfactory for most conditions, the use of a low-speed type of motor being one of the causes of the low efficiency of the earlier electric cars. Another reason was the employment of two motors on comparatively light cars. This had a certain advantage in eliminating the differential, but its electrical efficiency was very low. Modern practice does not sanction the employment of more than one motor on even the heaviest of pleasure cars and on commercial vehicles up to 3- or 5-ton capacity. Beyond that point practice varies somewhat, some makers employing two driving units on the ground that no differential is needed, that starting torque is bettered by connecting the armature in series, and that damage to one motor will still permit the vehicle to travel. These advantages are more than offset by the higher efficiency possible in a single and larger electric motor, beside the benefits derived from the saving in weight of the motor and from the ability of the manufacturer to combine the two speed reductions necessary with two motors into one. This avoids some power loss in transmission from the motor to the driving wheels.

THE TRANSMISSION

Similarity to Gasoline Practice. The types of power transmission on the electric vehicle have been the same as on the gasoline car except that the order of their application has been chronologically reversed. The latter started in generally as a chain-driven machine, and quite a number of years elapsed before any other method of transmitting the power to the rear wheels was attempted. The electric, on the other hand, began as a gear-driven car, as the practice of direct-connecting electrical generators and power units, which first assumed a strong vogue shortly prior to the advent of the electric automobile, was taken as a precedent. From the point of view of operating conditions, there is considerable similarity between the gasoline and the electric machine as far as its power transmitting system is concerned.

Usual Gear Reduction. Owing to weight and space limitations, the size of the motor is correspondingly limited, and it is accordingly necessary to employ high initial rotative speeds, i.e., a very high-speed motor is essential in both cases, while the starting torque or pull must likewise be very strong in order to enable the vehicle to get under way quickly and to start readily on grades. This necessitated gearing down to a very great extent, the usual ratio on the majority of the electric vehicles being 10 to 1, i.e., for every ten revolutions of the motor, the road wheels make but one turn. In order to accomplish such a reduction without employing gear wheels of a prohibitive diameter, it was necessary to bring about this lowering of the motor speed by means of two steps, or a double train of gears. Spur, or plain straight-tooth, gears were employed at first, and proved to be not only noisy, but very wasteful of power.

They were accordingly replaced by chains in many instances, and by gears of special types, such as the *herringbone reducing gears* of the Waverley. In some instances, such as the light Baker runabout placed on the market several years ago, it was found possible to drive directly from the motor to the rear axle through the medium of a single chain, but with this exception the custom of employing two distinct reductions of speed was generally followed up to a year or two ago. While there were several variations in the manner of accomplishing this, the general principle was practically the same

in every instance, a single chain being taken from the end of the armature shaft of the motor to a countershaft éxtending clear across the car and having sprockets at each end. The reduction in speed from the motor to the countershaft was usually about five to one, and a similar second reduction was carried out by means of small sprockets on the ends of the countershaft, and large ones on the driving wheels. A third class of transmission consists of a combination of gearing and chain drive, such as were used on the earlier models of the Woods, and the Waverley electrics, the first reduction of which is a silent chain.

Chain Drive.— During the past few years, practice in the electric field has closely followed that of gasoline car transmission design,

Fig. 27. Gear Type of Transmission

where the final drive is concerned, and in some cases anticipated it. But for the advent of several low-priced electric cars, some of which have perpetuated the single-chain drive—using a roller-type chain and sprockets as the second step in the reduction—this form would have practically disappeared. It is efficient and reliable, but not as clean and sightly as the shaft type, though this objection may be readily overcome by enclosing the chain. Economy in initial cost is one of its chief advantages and, in the case of cars which are sold at a very low figure, this is naturally of paramount importance.

Gear Drive. The self-contained unit shown in Fig. 27 is an illustration of what might be termed an instance of reducing the power plant and final drive to the last degree of compactness. Referring to the figure it will be noticed that the usual type of motor is mounted on a forward extension of the rear axle, the first step in the speed reduction being a pair of herringbone gears. Apart from this, it is practically a replica of gasoline car practice, as the axle is of the full floating type commonly employed on the latter, the second

Fig. 28. Well-Designed Unit of the Shaft-Driven Type with Bevel-Gear Rear Axle

speed consisting of the usual bevel drive, except that the propeller shaft is only a few inches long and consequently does not require any universal joints. A somewhat similar type of transmission is employed on the Broc electrics. A *full floating* type of axle with shaft drive is also a feature of the Borland, this form taking its name from the fact that the two driving shafts are not rigidly fastened at either end—either the differential or the driving-wheel end—the power being transmitted through a square-ended section of the shaft *floating* in the differential and a jaw or similar type of clutch at the wheel, the entire weight of the

car being carried by the tubes or axle housing. An example of a single reduction-shaft drive is to be found in the Century, using a Timken bevel-gear rear axle.

An equally compact form which gives a better weight distribution is the drive illustrated in Fig. 28. This bears a very strong resemblance to the driving unit of a well-known light gasoline car. It is a type which affords great rigidity with a very simple construction. The propeller shaft is practically a continuation of the armature shaft, no universal joint being necessary. At its after end this shaft meshes with a bevel gear giving a reduction of 2 to 1, while a spur-pinion reduction lowers the ratio again 4 to 1, or a total of 8 to 1 between the high-speed motor and the driving wheels.

Fig. 29. Combined Bevel and Spur Gear. Double Speed Reduction of the Axle Shown in Fig. 28.

The arrangement of the two speed reductions in the axle is shown by Fig. 29. These bevels have an adjustment by means of a collar which can be loosened or tightened until a perfect adjustment is obtained. The larger bevel is mounted on a short jackshaft carried on ball bearings on both ends, and upon this shaft is mounted the small spur pinion. On each side of the jackshaft is a threaded collar which allows for the movement of this shaft either in or out, which, in conjunction with the adjustment of the bevel gears, permits of a perfect setting of both sets of gears. The housings consist of tapering swaged steel tubes which extend from each side of the differential housing through the brake housings and the wheels, while the driving effort is taken on the combined torsion and radius rods pivoted on saddles on the axle just inside the brake drums and on the rear end of the motor housing.

In this, as in all representative types of final drive on electric pleasure cars, annular ball bearings are used throughout. One of these bearings is shown just forward of the small bevel pinion in the two-speed reduction axle. This is an advanced type of bearing which the automobile has been largely responsible for developing. It is far more costly than even the very best of plain bearings, but it cuts friction down to a practically negligible factor, while it will also run with a very small supply of lubricant and requires a minimum of attention. Such bearings are now universally employed, not alone in the electric motors of these vehicles, but also for the countershafts and wheels, and in similar locations. If the ball bearing is not employed, the taper roller type is substituted, the latter being very much favored for wheel bearings on both gasoline and electric cars, owing to their ability to withstand heavy thrust as well as radial loads.

Worm Drive. *Development.* What would appear to be the ultimate development in electric car transmission, however, has been the adoption of the worm drive; and, in taking it up so generally, the electric vehicle manufacturers have anticipated what is bound to come on the gasoline pleasure car in the near future, as it already has in England to a great extent. In this adoption, the history of the electric self-starter on the gasoline car has been repeated, in that experiments were carried on for a number of years with little progress apparent to the world at large, and then, within a comparatively short time, the worm drive came into more or less general use. In this case, however, most of the research work was carried out in England, and a considerable proportion of the worm drives used on American electric cars are imported from that country. In itself, this form of drive is not a novelty, the Hindley worm drive, made in Philadelphia, having been employed on electric elevators for quite a number of years. Its successful application to the automobile represented far more of a problem than the bevel-gear type as, unless correctly designed and machined to the highest degree of accuracy, the friction and thrust are excessive and the resulting efficiency is low.

Advantages of Worm-Gear Transmission. Consideration of the fundamentals of electric vehicle design, i.e., a light high-speed motor and a comparatively slow axle speed, will make apparent the

great desirability of the worm drive in this connection. It represents the most practical means of power transmission from a high-speed motor direct to the rear axle by means of a *single reduction*. This means saving in weight and the avoidance of the power loss entailed through the use of the second reduction in the gear ratio otherwise necessary. A further advantage is its silence in operation, the worm and worm wheel representing the closest approach to this much-to-be-desired feature that is attainable in the transmission of power by direct metal contact. While its initial cost is as high, if not higher, than even the best forms of double reduction, it eliminates several parts, and accordingly affords a simpler form of construction with a more direct transmission of the power.

Fig. 30. Rauch and Lang Worm and Gear

Details of Worm Drive, Rear Axle, and Brake. The worm is of alloy steel while the worm wheel is bronze, a multiple thread of long pitch being cut on the former while the latter is made with a special form of tooth, as will be noted by the Rauch and Lang worm shown in Fig. 30. This is an American type developed by the makers of the Rauch and Lang electrics especially for this purpose. In both this make and the Woods electric the worm meshes with the worm wheel on its upper side, the relation being shown by Fig. 31, which illustrates the Rauch and Lang motor and propeller shaft in addition. Two universal joints, one of them of the slip type to allow for relative longitudinal movement between the motor and rear axle, are employed. A brake is placed on the forward end of the armature shaft, this showing in the same illustration. Fig. 32 shows the complete Rauch and Lang motor and driving unit. A torsion

rod, parallel with and below the propeller shaft, also serves as a distance rod between the motor and rear axle and takes all torsional or twisting stresses to which the axle is subjected when under power. The forward end of this torsion rod is connected by means of a

Fig. 31. Rauch and Lang Motor, Shaft, Universal Joints, and Worm and Gear

flexible joint of the ball-and-socket type, with the top of the torsion rod link, which in turn swivels on the rear motor yoke. The rear end of the torsion rod is taper fitted into a nickel-steel forging, which

Fig. 32. Rauch and Lang Motor and Rear Axle Unit

sets into a vertical taper bearing in the front end of the axle housing. The method of hanging the torsion rod leaves the rear axle housing perfectly free to adjust itself to the relative movement of the axle and frame due to the compression of the springs. The latter are of the seven-eighths elliptic type, the upper and lower members of

Fig. 33. Rear View of Rauch and Lang Worm Drive Chassis

which are shackled at the rear ends so that they are flatter than usual, thus giving better riding qualities. They are held at three points, which decreases the tendency toward lateral movement or side sway, the driving strains being taken on the front ends of the lower leaves. The worm and worm wheels are adjusted in perfect alignment in assembling the unit, and the latter is housed in, so that no adjustments can be made from the outside. Contrary to the bevel-gear drive, which in course of time wears out of alignment, a worm gear continues in alignment regardless of wear, within prac-

Fig. 34. Forward End Torsion Rod, Spring Suspension and Brake Details on Rauch and Lang Car

Fig. 35. Details of Rear Wheel Brake Construction as Employed on Several Makes

tical limits, and once properly adjusted can only be deranged by subsequent adjustments. A better idea of the various essentials of the drive will be obtained by reference to the rear view of the Rauch and Lang worm-driven chassis, Fig. 33. As mentioned previously, a brake is carried on the armature shaft on this car, the second set being of the internal expanding type operating against the drums shown attached to the driving wheels, Fig. 34. On the

Fig. 36. Detroit Worm Drive, Rear Axle and Motor
Courtesy of Anderson Electric Car Company, Detroit

Argo and several other cars both sets of brakes are of the internal expanding type, the details of this type of brake construction being shown in Fig. 35.

This is likewise the case on the Detroit electric, the rear axle unit of which is shown in Fig. 36, the details of the brake construction appearing plainly. The Lanchester (British) type of worm is employed on this car. As will be noted from the part sectional illustration, Fig. 37, the worm drives through the lower part of the

Fig. 37. Lanchester Worm Gear Used on the Detroit Electric Car

worm wheel and runs in a bath of oil, the oil level being shown in the figure. In the types previously described, the worm-wheel housing itself is partly filled with heavy oil.

This sectional illustration also shows a marked difference in pitch of the worm thread as compared with the Rauch and Lang, and makes clear the detail of the mounting. The latter consists of a combination radial and thrust annular ball bearing at each end of the worm and on each side of the worm wheel. Upon the correct

alignment of its mounting and proper provision for taking the thrust, quite as much as upon correct design and accurate machining, depends the success or failure of any worm drive.

THE CONTROL

Unlike the gasoline car, in which the control of its speed and climbing abilities is divided between a provision for changing the gear ratio existing between the motor and the driving wheels, and a means of increasing the speed and power output of the motor itself through the admission of more fuel and advancing the point of ignition, that of the electric vehicle is entirely electric. This is largely responsible for its great simplicity, all changes in either direction being effected through a single small lever, the manipulation of which calls for no more skill than the shifting of a trolley-car controller. But there is quite as much latitude of design to be found in the methods of control of electrical vehicles as there is in the method of transmitting the power to the rear wheels, though, as in the case of the power transmission, there is more or less similarity in the principles involved

Counter-E.M.F. Neither a steam engine nor a gasoline motor can be given "full throttle" to start it without danger of damaging it. This is due to the inertia of the moving parts, which must be set in motion gradually and allowed to attain a certain speed before full power is developed. As the electric motor has no reciprocating parts, and its revolving armature is carried on the finest type of anti-friction bearings, the factor of inertia is practically negligible in so far as it affects starting. It has already been mentioned that the passage of too great an amount of current through a wire, i.e., too great for its carrying capacity, has a heating effect. The heating increases in proportion to the excess of current flow over the safe capacity of the wire until it is sufficient not only to burn off the insulation on the wire, but even to fuse the wire itself.

Now the resistance of the motor armature windings is very low, but when the armature is revolving, the electrical resistance is increased by two factors—first, a counter-e.m.f., which is developed by virtue of the rotation of the armature, and second, the fact that the wire in the windings becomes warmer, it being a peculiar and

inexplicable phenomenon that the resistance of a wire increases in proportion to its temperature.

Controller. The inability of the motor to carry more than a fraction of its normal operating current when starting makes necessary the use of something equivalent to the throttle of the steam engine for accomplishing this necessary control. As not alone the character of the external source of power—in this case the battery—is capable of manipulation, but also the internal relations of the power-producing elements of the motor itself—the armature and the field—are susceptible of various changes, it will be evident that the speed range possible under the circumstances may be made as

Fig. 38. General Electric Controller

wide as the designer desires. Ordinarily, most electric vehicles are provided with a controller giving five speeds forward and two or three reverse.

Drum Type. In the majority of cases, the controller employed on the electric automobile is of the drum type, and is practically a duplicate on a reduced scale of that employed on street railways, except that the automobile controller is what is known as a *continuous torque* type. That is, there are no dead spots or idle gaps between different speeds, the current always being on except when the controller handle is at the neutral position. This insures a continuous and gradual increase in the speeds without any jerking between the various steps, and prevents a sudden heavy load being placed

on the motor, as would be the case where a pause was made in shifting the handle of the controller over a dead gap. The motor continues to run at the lower current value until the next set of contacts on the controller is actually delivering a greater voltage or more current. The drum, or cylinder, is of insulating material and has mounted on it a number of copper segments of substantial thickness. These are so spaced that they make contact with corresponding fingers, also of heavy spring copper, that are held stationary alongside the drum. The copper bars on the drum are "grounded" to provide the continuous torque, that is, they have a common return permitting

Fig. 39. Controller of the Detroit Electric
Courtesy of Anderson Electric Car Company, Detroit

the current to reach the motor constantly, i.e., while changing speeds. A controller of this pattern is shown in Fig. 38, which is of General Electric make.

The drum in this instance is seen to be but a section of a cylinder, on the curved surface of which the spacing of the bars will be apparent. It will also be seen that there is a corresponding finger making contact with each bar, or in a position to do so when the drum is turned to bring it around to that particular point. These fingers are held against the drum very firmly by springs. The open socket visible at the lower end of each finger is intended to receive the bared copper wire of which it represents the terminal connection. A variation of this type of controller is shown in the illustration, Fig. 39, and

it will at once be evident that it is provided with a greater number of contacts than is the first controller shown. It should be mentioned here that the drum is spring controlled as well as the contact fingers, and is also provided with notched stops in order to hold the contacts on it directly under the ends of the fingers. In the present instance, which represents the type of controller employed on the Detroit car, the contact fingers themselves are directly attached to leaf springs, which are plainly in evidence. The terminals mentioned are also to be seen along the bottom, while at the left there is an extension of the shaft on which the drum is mounted. This carries a

Fig. 40. Chassis of Detroit Electric Car

lever by means of which the drum may be revolved in order to give the different speeds, forward and reverse. The latter is generally accomplished by means of a pole reversing switch, most frequently incorporated directly in the controller itself, and which always remains locked under normal running conditions. In order to bring the reverse into play, it is usually necessary to depress a small pedal or similar release, in order that the driver may not inadvertently start the car backward. A view of the Detroit chassis is shown in Fig. 40.

Flat Radial Types. A good illustration of a totally different form of controller is found in the Rauch and Lang cars, and is known as the *flat radial* type. In the construction of the earlier models of the Rauch and Lang car, it was combined with the motor

and countershaft unit, but is now mounted independently and in the accompanying illustration, Fig. 41, it is shown separately. Instead of being mounted on a drum, the contacts are placed on a stationary segment representing about one-fourth of the arc of a circle. A pivoted arm, held at what would be the center of the circle, is so mounted that it may be turned in order to make contact with the different blocks, these in turn being electrically connected to the terminals shown attached to the upright piece at the left of the controller. As a matter of fact, there are two separate series of contacts around the arc, and two movable levers arranged to be moved over them. In this case, the moving

Fig. 41. Flat Radial Controller

Fig. 42. Flush Type of Controller

contacts are made of thin copper leaves assembled together and are held against the contacts by a spring.

Flush Types. Fig. 42 illustrates a type of controller which is designed to be countersunk in the seat of its surface so as to be flush with the latter. This is a plan view, showing the controller as seen from above, the pattern being one in which the drum is a complete cylinder. The left-hand panel of the controller holds the fingers and contacts for the forward speeds, while those at the right are the reverse speeds, there being four in each direction in this case. Further to the right is to be seen the operating lever, the pinion visible on the end of the drum shaft constituting part of the mechanism for advancing or returning the drum. This consists of a rack in the shape of a quadrant which meshes with the pinion in question. At the extreme left is shown the spring-controlled stop which prevents the drum from being rotated more than one space at a time in either direction, and holds it with the fingers pressing directly on the contacts at each point of its revolution. The type of controller employed on the Baker cars is shown in Fig. 43.

Fig. 43. Baker Controller and Operating Lever

Magnetic Type. To facilitate the handling of the comparatively heavy current that is necessary in starting, changing speed in going up hill, and the like, without having to employ wiring of large size to a point near the hand-control lever, a modification of the multiple-unit system of control as used in electric railway service, and particularly on elevated trains, has been applied to the electric automobile. In this system only a current of small value is actually passed through the hand-controlling mechanism, which takes the form of a small "controller box", as shown in Fig. 44, which represents part of the control of the Ohio. The controller of the Century is shown in Fig. 45. By setting this to the speed desired, current is passed through a magnet in the controller proper. The armature of the magnet is attracted, and in so doing it closes a switch or contact for the corresponding speed. There is a magnet or solenoid for each speed ahead and reverse, which are so connected that, in

changing to a higher speed, the contact of the speed below is not broken until either the switch giving the higher current value is closed, or the current is shut off, thus releasing all the magnets and

Fig. 44. Control Disk of the Ohio Magnetic Controller
Courtesy of Ohio Electric Car Company, Toledo, Ohio

obtaining the advantages of the continuous-torque type of hand controller. The arrangement effected by the opened and closed positions of the various magnets determines the direction and

Fig. 45. Magnetic Controller of the Century Electric Car

magnitude of the current in the motor circuit in a similar manner to that provided by the segments and fingers of the drum controller. The essential difference between the magnetic controller and the

ordinary type is that the former is electrically operated, while the latter is mechanically operated. Hence its location is not governed by the necessity of mechanically connecting it with the hand lever through rods, gears, or chains, and it may be placed in any convenient location. In the Ohio it is placed under the seat. The various speeds are obtained by turning the disk on the end of the contactor box near the driver's hand. Turning to the right gives

Fig. 46. Wiring Diagram for Primary Circuit of the Ohio Magnetic Controller

the various forward speeds in consecutive order. The neutral position is as far to the left as the disk will go; by pushing the button on top the controller may be turned still further to the left to give the reverse speeds. When in the neutral position it may be locked there by pushing in the button at the back, and the controller cannot then be operated until unlocked with a key. Buttons are also provided for ringing the bell and operating the magnetic brake. The contacts are made by spring-held carbon brushes pressing against the inner face of the disk. In this system of control there are two independent circuits—the primary circuit passing through the mag-

netically-operated switches of the controller from the battery to the motor, and the secondary circuit, which handles the current of lesser value employed to operate the magnets, and which is controlled by the movement of the disk mentioned. The primary wiring diagram of the Ohio is shown in Fig. 46, and the secondary wiring diagram in Fig. 47.

Duplex Control. To facilitate the handling of closed cars of the brougham and other large types of enclosed cars seating five or more passengers, duplicate-control wiring and duplicate-brake pedals

Fig. 47. Wiring Diagram for Secondary Circuit of the Ohio Magnetic Controller

are provided at two positions; one forward, designed to be operated from a front seat, and the other similarly located with relation to the rear seat on the same side. Brake pedals and steering connections are also duplicated, so that to shift the control of the car from one location to the other, it is only necessary to release the steering column at one place and insert and lock it in the socket provided for this purpose at the other. This enables the driver to keep the way clear ahead no matter how many passengers are carried and also drive from the rear seat when the load is light.

Care of Controller. The contacts of the hand-operated type of controller should be inspected at intervals to note whether they are

making proper contact or not. In case the spring of one of the fingers loses its tension, an arc is apt to form between it and the segment on the drum and burn the metal. The presence of such an arc will be noted by a peculiar hissing sound which will be plainly audible if the cover of the controller box is removed and the car run in a comparatively quiet place. This action will also take place to a certain extent if the controller is held between the notches in changing speed. The blistered surface of the metal thus resulting will make poor contact, and will continue to burn more and more unless this condition is remedied by sandpapering the finger and correcting the tension of the spring so that contact is made all over the surfaces that touch. If a finger has become badly burned, it should be replaced and the new one adjusted to an even, moderate tension. When necessary to face the fingers to the drum, the sandpapering should be done on the fingers themselves rather than on the segments of the drum, as the latter are not so easy to replace. The drum segments should be kept bright and clean, and should be lubricated occasionally by wiping with a linen rag and some vaseline.

Methods of Control. As it is equally important for the owner of an electric vehicle to familiarize himself with the manner in which the amount of current sent through the motor is controlled, quite as much as with the apparatus for effecting this, it has been thought advisable to devote a short section to this subject. Before taking up this matter, it will be well to return momentarily to a previously discussed subject of series and parallel connections.

Series and Multiple Connections. Each cell of a storage battery is a complete self-contained unit capable of delivering current of a certain amount according to its size and capacity, at an electrical pressure of slightly more than two volts when fully charged. For purposes of illustration, each individual cell may be likened to a pump, capable of exerting a pressure of two pounds. It will be quite apparent that if 24 such pumps, corresponding to the 24 cells of a 48-volt storage battery, were connected together—the outlet of the first to the inlet of the second and so on throughout the entire 24—the series of units would be capable of producing a pressure of 48 pounds. The water delivered could accordingly be forced 24 times as far, or as high, as one pump could send it, but the quantity raised would only be that of which one unit was capable. This analogue

affords a very clear idea of what is meant by a series connection, as the statement just made regarding the ability of pumps so connected applies literally to the storage cells under the same conditions. Again taking the 24-cell battery as an illustration, this being the former standard for light pleasure vehicle use, it will be seen that the output of the battery connected in series, i. e., the positive of one to the negative of the next and so on throughout the set, would be the ampere-hour capacity of one cell at 48 volts. The voltage is seldom constant, but ranges from 2.2 to 1.7 volts per cell, according to the state of charge that the cell is in at the time; but when a number of cells are connected in series, the voltage of the battery thus formed will always be that of the voltage of one cell multiplied by the number in the battery. For purposes of reference, it is customary to consider the potential of the storage cell as 2 volts.

To return to the analogue of the pumps, where the conditions are such that a greater quantity of water is required, but it is not necessary to raise it to more than half the height to which the 24 pumps in series are capable of sending it, they may be arranged in two series of 12 each. Double the volume of liquid may then be raised to a height represented by the ability of the 24-pound pressure developed. The two groups of pumps are still in series, so far as they alone are concerned, and each group would have but the capacity of a single pump at twelve times its pressure. But when the inlets and the outlets of the two groups are brought together in the case of either pumps or storage cells, the volumetric capacity is increased to two units at a pressure of 24 pounds or volts. If, on the other hand, all the inlets were brought together into one connection and all the outlets into another, there would result a capacity of 12 pumps, at the pressure of but one. This last-named arrangement is termed a *multiple* connection, while that described above is a combination of the series and multiple connections, and is accordingly designated by the term *series-multiple.*

Given 24 cells or more, the number of series-multiple combinations possible is quite extended, but it will be evident that those at either extreme of the range would be useless for all practical purposes in the running of an electrical vehicle. It is accordingly customary to assemble the cells in sets of six or eight connected in series, which cells are securely packed in oak cases, the number of the units

employed depending upon the voltage of the motor of the vehicle.

Resistance in Circuit. Another source of control is to be found in the motor itself. It will be recalled that the latter generates power by means of the alternating magnetic attraction and repulsion of the sections of the armature by the field magnets. The strength of the latter, as well as that of the electromagnets composing the armature, is naturally dependent upon both the amount of current sent through them and its voltage. One of the simplest forms of control is naturally that in which the entire battery is in series with the motor, and in which the relation of the two undergoes no change. In such a case, resistances of the type shown in Fig. 48 are employed

Fig. 48. Controlling Rheostat

to cut down the current sufficiently to give what are usually termed the *starting speeds*. In every case, the full energy of the battery is being drawn upon, but only a part is being utilized on these first speeds, the remainder being dissipated by the resistance in the form of heat. In view of the very short period during which they are employed, the use of resistances in these starting speeds is not a detriment. This system of control is to be found on the Rauch and Lang cars, among others, and has the great advantage of discharging all the cells of the battery uniformly. All the speeds are obtained at the same voltage and the motor is working at every position of the controller handle, so that there are accordingly no dead spots and the circuit is never open, even momentarily. A similar system of

control is employed on the Baker vehicles. This will be evident upon a little study of the accompanying diagram, Fig. 49, illustrating the wiring and all the connections. The large squares, marked plus and minus, represent the groups of cells into which the battery is divided. The individual cells in each group are connected in series and it will be seen by tracing the connections that the groups are likewise in series, a positive being connected to a negative and so on throughout.

Wiring Diagram. Wiring diagrams appear extremely intricate to the uninitiated at first sight, but in each instance the course taken by the current may easily be followed after a little study, and as familiarizing himself with all the wiring and connections of his car is a

Fig. 49. Control Wiring Diagram

part of the education that no electric vehicle owner should overlook. it should not be slighted. The diagram received from the manufacturer of his car will be a blue print similar to the one from which the accompanying illustration was taken, so that it may be studied here as well as at first hand. Familiarity with one of these diagrams will prove an "open sesame" to all others, for, while they all differ to a greater or less extent, it will be easy to trace the different circuits, once the rudiments are known.

The fact that all of the cells in the battery are in series has already been mentioned. It will be seen that there are 24 cells in the battery, giving a working potential of 42 to 60 volts according to the state of charge. The different points of the controller are represented by the group of parallel bars in the lower center of the

drawing, marked *R*-4, *R*-2, etc. In this case it will be noted that there are four connections of this nature, *R*-1 to *R*-4, these representing resistances to cut down the current for starting. They are accordingly known as *starting speeds,* and are only designed for getting the vehicle under way, an operation that calls for a heavy torque or pull on the part of the motor. This requires a large amount of current and, as already mentioned, it would be apt to burn out the motor windings if sent through the latter before it had attained sufficient speed to build up its counter-e.m.f. to a point where the full current may be safely handled. The external resistances themselves are represented by the bars marked in the same manner, seen diagonally to the left and above the controller on the diagram, the connections between the two being easily traceable.

Further points on the controller are designated as *F*-1 and *F*-2, and *FF*-1 and *FF*-2, and refer to the connections for altering the relation of the field and armature. Electric motors employed on automobiles are generally of what is known as the *series type* in which the armature and fields are normally in series with one another. In other words, the entire current passes through the complete winding of the motor. By varying this relation in several ways, several steps in the speed control are possible without the intervention of any resistance. For instance, in the control, as illustrated, the first speed is obtained by placing the field in series with a resistance, giving a car speed of 8 miles an hour. By cutting out part of the resistance and still maintaining the same relation, the car speed is increased to 10 miles an hour, corresponding to the second point on the controller. At the third point, the resistance is eliminated altogether, resulting in an increase to 12 miles an hour. A further increase to 14 miles an hour is obtained by shunting the fields, while the fifth speed of 16 miles an hour results from placing the field in series-multiple. The last point on the controller shunts the series-multiple field and gives 19 miles an hour.

Office of the Shunt. The term *shunt* may be explained by turning again to the water analogy. Electricity, water, or anything else under pressure will naturally follow the path of least resistance. Take, for instance, a two-foot water main, with a one-inch outlet tapped into it. The amount of water that will flow through the one-inch pipe is not alone dependent upon the pressure

in the main, but likewise upon the resistance offered by the one-inch pipe. This, by analogy, is practically an application of Ohm's law. Substitute for the water main an electric circuit. At a certain point, connect to it a by-path in the shape of another circuit of smaller wire, and in consequence, representing a greater resistance. The current can pass through these two circuits simultaneously and the amount of current in the second, or shunt circuit, will be smaller than that flowing in the main circuit. In fact, the current will divide itself inversely as the resistance; that is, if a shunt has ten times the resistance of the wire in the main circuit between the terminals of the shunt, this shunt circuit will carry only one-tenth of the total current.

The best example of a shunt connection is to be found in the case of the volt-ammeter, as shown in Fig. 49. For convenience, the voltmeter and ammeter (ampere-meter) are combined in a single case as if they were one instrument, but it will be noted that the connections are the same as if both were independent. As the voltmeter is always in circuit, whether the car is running or not, it is wound to a very high resistance so as to consume the minimum amount of current for its operation. The shunt marked on the lower part of the diagram, just under the position of the instrument, is really a part of the ammeter itself. Where only small quantities of current are to be measured, the full strength is usually passed directly through the ammeter, but on an electric automobile, this would not be practicable in view of the wide range and the sudden variation of the storage-battery current, which in starting frequently takes the form of a heavy surge. The instrument is accordingly designed to employ but a fraction of the total current, this fraction bearing a direct relation to the total current passing, the scale reading of the ammeter being the same as if the full strength of the current passed through it.

It will be evident that any circuit, such as the field winding of the motor, when placed in shunt with its supply circuit, will only take an amount of current depending upon the ratio between its resistance and that of the main circuit, and that economy in current consumption results. This explains its employment for two of the higher speeds of the car, the wiring diagram of which is illustrated in Fig. 49. It will be noted that this connection is only employed for the higher speeds; in one case, the field windings being in series them-

selves, and the whole in shunt with the main circuit, to give 14 miles an hour; and in the second, the field windings themselves being in series-multiple and in shunt with the main circuit to give a speed of 19 miles an hour. This is due to the fact that at the higher speeds, only a relatively small amount of power is required to keep the machine moving. Electric vehicles as a rule do not run at speeds high enough to make wind resistance a factor of great importance, and as a result operate under ideal power conditions when once under way. In other words, the *draw-bar pull*, by which is meant the effort necessary to keep the vehicle moving, is very light. At starting, however, in common with other cars, it is heavy, so that it will be evident that the shunt connection is not applicable to the starting speeds. Its rôle is that of economy, rather than power, and to obtain the latter the series connection is necessary.

Fuses. The fuses are a part of the electrical equipment of the car, mention of which may be appropriately made in this connection, as their function is that of acting as a safety valve in the control. The varying resistances of different kinds of metals have been explained, as well as the heating effect incident to sending a current through a wire, particularly where the latter is of a size too small to carry the current. It is well known that lead and similar materials have a very low melting point, and advantage has been taken of this in connection with the phenomenon just referred to, to make what are known as *electric fuses*. These are strips of lead alloy of accurately determined sizes, each size being designed to carry a certain amount of current at a certain voltage. This is known as the *capacity* of the fuse, and between it and the amount of current that the motor or other apparatus which the fuse is designed to protect can safely stand there is an ample margin of safety. In consequence, whenever there is a rush of current through the circuit, as when the controller lever is pushed sharply forward toward the *full on* point, and the brakes happen to be holding the car, the fuses will "blow out" or melt, and save the motor from destruction.

Electric Brake. In addition to the usual mechanical brakes, the construction of which is along lines practically identical with those employed on gasoline cars, some manufacturers equip their cars with an electric brake. Just how this acts will be clear from a perusal of the chapter devoted to a description of the motor and its method of

operation. It will be evident that upon reversing the function of the motor and driving it from an external source of power, which in this case will be the motion of the car itself, it will act as a generator of electric current, and in doing so, it will absorb power in proportion to the speed at which it is driven. Connections are accordingly provided on the controller to permit of this, but the motor provides such an extremely powerful brake, that this has been regarded as a disadvantage in some cases, so that certain makes of electrics are only equipped with mechanical brakes.

This disadvantage is doubtless due to the fact that the series type of motor ordinarily employed on the electric car does not lend itself readily to this service. Its *braking power* increases as the square of the speed of the car, i.e., at sixteen miles an hour, the effect is four times as great as at eight miles, and when suddenly applied this is apt to stop the car very suddenly, much to the detriment of its tires and mechanism, if not to the occupants themselves. Should a small particle of dust or burnt metal lodge on a contact and momentarily prevent the brake from "taking hold", the motor will suddenly "build up", with disagreeable results.

DETROIT ELECTRIC BROUGHAM, MODEL 60

Courtesy of Anderson Electric Car Company, Detroit, Michigan

ELECTRIC AUTOMOBILES

PART II

CARE AND OPERATION OF THE ELECTRIC

CHARGING THE BATTERY

SOURCES OF CHARGING CURRENT

Sources of Direct Current. *Small Generators.* There are few towns, or even villages, in this country at the present day that cannot boast of electric-lighting facilities, so that the owner of an electric vehicle will find it possible to obtain charging current for the maintenance of this type of automobile regardless of where he lives. In case he should reside too far outside the corporate limits of a village to find such service at his command, or in case he is of a sufficiently mechanical turn of mind to undertake it, he will find apparatus for generating the current on his own premises available for a comparatively moderate outlay. Though not the simplest, a small direct-current dynamo driven by a gasoline engine requires but little attendance, and will prove by far the most economical method of charging. This is particularly the case where the generating set's chief employment is that of lighting the house, although where an isolated plant may be installed, the owner of an electric vehicle will find it a great advantage for charging purposes alone.

This may be seen from the fact that in small towns and villages rates for electric current are usually high. The power unit, the *watt*, has already been explained. A kilowatt is 1000 watts, and electric current is sold by the kilowatt hour, which means the employment of one kilowatt of current for one hour. Where current is purchased in comparatively small quantities, the rate is seldom less than 10 cents per kilowatt hour, and sometimes 15 cents, or more. With an ordinarily efficient generator and gasoline engine, current may be produced in a small isolated plant for less than 5 cents per kilowatt hour.

The average runabout battery requires 75 to 80 ampere hours

for a charge, while a surrey, phaeton, victoria, brougham, or similar type will need 100 ampere hours. Current is charged for by the watt hour, which is a current of one ampere at a potential of one volt, flowing for one hour.

Service Mains. If the current be taken from the service mains at 115 volts, the charge for the runabout battery would be $75 \times 115 = 8625$ watt hours, or more than $8\frac{1}{2}$ kilowatt hours. The cost of this would be 86 cents at a 10-cent rate. Even where current is to be had at more favorable rates, such as 7 or 8 cents a kilowatt hour, a small engine and dynamo are very much more economical where no extra attendance has to be figured on. That is, where there is a man of all work about the place, this is something that may well fall within his province. Where the generator may also be used for lighting, the cost for charging will be reduced to a minimum. In the majority of instances, however, the difference in the cost of charging the battery in this manner will not be found to represent a sufficient inducement to make it practical to undertake the initial outlay required for a small current-generating plant, although the saving over a period of two or three years would represent no inconsiderable offset to the original investment.

Street Railways. Direct-current service is now seldom obtainable, except where concessions may be made to the automobile owner by the local street railway. In the latter case, current is usually obtainable at a lower rate per kilowatt hour than would be charged by a lighting company, but the advantage is not as great as would appear at first sight, owing to the higher voltage. Current from a trolley line would be at 550 volts, and the difference between the latter and the voltage required to charge the battery would represent a loss, as it would have to be dissipated through a resistance. The ability to utilize the current from street-railway mains, particularly where long tours have been undertaken, has often proved a great help, however, and where no other service is available it may be employed regularly for charging by installing apparatus for handling it. Although a shock from a circuit at this voltage (550) is not generally considered fatal, it so often proves otherwise that its use involves an element of danger.

Sources of Alternating Current. Turning now to the usual source of electricity, the *alternating current*, one is confronted with

Fig. 50. Motor-Generator Set, 115 A. C. to 125 D. C.

the fact that the *charging current must in all cases be "direct", never "alternating"*.

Alternating current has been found much more practical for long-distance transmission and distribution, and its use is now very general throughout the country, so that where the owner of an electric

Fig. 51. Motor-Generator Set, 220 A. C. to 110 D. C.

vehicle decides to fit up his own garage for storing and charging the car, the first thing to be considered will usually be some means of rectifying the alternating current, that is, making it direct. This may take several different forms, such as the motor-generator set and the mercury arc rectifier, but for reasons which will be made plain the mercury arc rectifier will be found the most practical and economical apparatus for the purpose.

Motor Generator. Where there is a considerable amount of charging to be done, the motor-generator set is frequently employed.

Fig. 52. Motor-Generator and Charging Panel for Charging Twelve Electric Trucks
Courtesy of Curtis Publishing Company, Philadelphia

This consists of an alternating-current motor and a direct-current generator combined in a single unit, both armatures being on the same shaft, the supply current simply being utilized to run the motor. A set of this kind is shown in the accompanying illustration, Fig. 50. It has two great drawbacks for private use in that the initial investment is high and that skilled attendance is required. Its efficiency is also comparatively low, particularly at light loads. Fig. 51 shows a smaller type of motor-generator set. In the first case, the apparatus is designed to take alternating current at 115 volts and generate a direct current at 125 volts; while in the second

instance the alternating current is 220 volts, and the direct 110, but such sets are obtainable for any commercial voltage and frequency of alternating current. In Fig. 52 is shown a very well-arranged and complete motor-generator charging plant.

Mercury Arc Rectifier. Owing to its simplicity, as well as to the fact that it entirely automatic in action, the mercury arc rectifier

Fig. 53. Switchboard, Front View

Fig. 54. Switchboard, Rear View

has come into very general favor for storage-battery charging. The outfits are compact and, while partly of glass, they are durable and easily installed. The apparatus itself is shown in Figs. 53 and 54, giving, respectively, a front and rear view; the connections are shown diagrammatically in Fig. 55. It will be seen that the panel board of the instrument incorporates everything necessary for regulating the charge, including a voltmeter, an ammeter, resistance, main switch, starting switch, circuit breaker, and fuses. The *circuit breaker* is a device designed to protect the apparatus with which it is connected by opening the circuit when there is an excess of current,

or when the current supply is accidentally cut off. By opening the circuit as soon as this occurs a rush of current through the apparatus is prevented when the service is resumed. Should it fail to act, the fuses represent the second step in the protective link, but naturally their only function is to rupture the circuit by melting under the heating effect of an excessive flow of current.

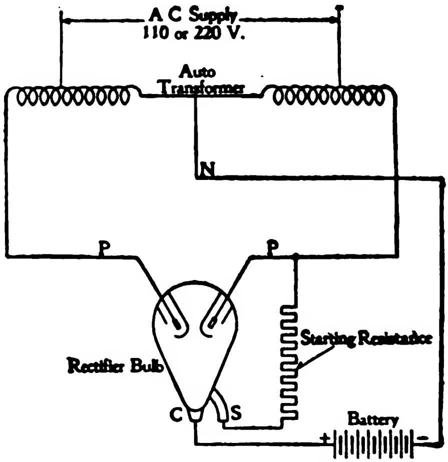

Fig. 55. Wiring Diagram for Mercury Arc Rectifier Circuit

As its name indicates, the mercury arc rectifier is an apparatus in which advantage is taken of a peculiar property of the electric arc when established in a vacuum and in the presence of mercury vapor. The device consists of a glass vessel, Fig. 56, from which the air has been exhausted and a certain quantity of metallic mercury inserted. The *tube*, as it is called, also has fused into the glass the several connections necessary. The one negative terminal, called the *cathode*, is sealed into the bottom of the tube while two positive terminals, called *anodes*, are on opposite sides and a short distance above the cathode. The anodes are graphite and the cathode mercury. When at rest, there is no electrical connection between them. A starting anode is accordingly provided. This is much smaller and is situated close to the cathode. If the tube

Fig. 56. Mercury Arc Rectifier Tube

be rocked gently after the switch has been closed, an arc is established between these two points. This liberates sufficient mercury vapor to start the main arc, and the apparatus is then in operation. As soon as this occurs, the starting switch is opened. A reactance coil, seen below the panel board in the illustration, completes the rectifier. It sometimes happens that the arc becomes accidently disrupted, regardless of the length of time the rectifier has been running, and to guard against stopping the charge in this manner, particularly where charging is carried on during the night, an automatic starting device is provided. This takes the form of a shunt coil and a solenoid, or hollow electromagnet, in which a plunger operates. When the arc is broken, the current is shunted through this solenoid and the plunger serves to shake the tube gently, exactly as when it is started by hand. This immediately re-establishes the arc and the charge is continued. Regardless of how often the main arc may be broken during the course of a charge, the rectifier is immediately restarted as long as the current is on. The theory of the transformation from alternating to direct current by the mercury arc is one of the most interesting of electrical phenomena, but, as the owner of the vehicle only is concerned with its practical side, it would be out of place here.

METHOD OF CHARGING

Making Proper Connections. At the present day, lead batteries are used almost exclusively for electric-vehicle use, and while different makes will vary slightly in design or construction, the differences are rarely material, so that the following description, as well as the terms given, applies equally to all. Batteries are not usually shipped with the vehicle itself, but are packed separately in a charged condition; as a freshening charge is required before the battery is used, it will prove an advantage to carry this out before placing the battery in the car. The groups of cells must be connected in series—the plus terminal of one group to the minus terminal of the next, and so on, *the final positive and negative terminals of the entire set being connected respectively to the positive and negative terminals of the source of the charging current.* The greatest care must be taken to see that the charging current flows into the battery at the positive pole, as sending a current through in the wrong direction will not

only fail to charge it, but will do a great deal of damage and seriously impair the life of the battery.

Determining Polarity. Where the polarity of the charging terminals is unknown, the simplest method of determining it is to take a glass of water into which a few drops of acid or a little salt has been put. Place the wires in it, *taking care to keep them well separated.* Bubbles of gas will form on both of the wires, but one will give off gas much more freely than the other. This is the negative pole and should be attached to the negative charging terminal of the battery. The other wire will give off comparatively little gas and will rapidly blacken. This is the positive pole. There are numerous other tests equally simple, but as this calls for apparatus easily obtained anywhere, it will be an advantage to memorize it, particularly as occasions will arise when the vehicle will have to be charged away from home in the absence of the usual facilities. The wire or connections to the battery from the charging side must be of ample size to carry the heaviest current used in charging without undue heating. The sizes used in the car itself form the best guide for this.

Voltage After Charging. The operation of charging will be the same whether the battery is in or out of the vehicle, but as the battery was fully charged when shipped, this initial charge will be a short one. But the greatest care must be taken to charge the battery fully. The voltage per cell should reach 2.55 volts, with the current still on, when the cell is fully charged. This would mean 60 to 62 volts for a 24-cell battery.

These voltages, Table II, are approximate and are intended for guidance only. A battery when cold will show a higher voltage than one at a higher temperature, and the same thing is true of a new battery as compared with an old one. It is not safe to regard a fixed voltage as the end of the charge, but a maximum voltage for the battery in question.

The rubber plugs should be removed from the cells during the operation, as the cells will be gassing very freely toward the end of the charge. This gas is hydrogen and, as it is not only highly inflammable, but likewise very explosive when mixed in certain proportions with oxygen, care must be taken not to bring a naked flame anywhere near the battery while in this condition. The plugs may be left out for a short time after the charge is finished to permit the

TABLE II

Charging Voltage for Lead Batteries*

Number of Cells	Volts At	
	Start	Finish
12	26	31
14	30	36
16	34	41
18	39	46
20	43	51
22	47	56
24	52	61
26	56	66
28	60	71
30	64	76
32	69	81
34	73	87
36	77	92
38	82	97
40	86	102
42	90	107
44	95	112
46	100	117
48	105	123
50	110	128

*Cushing and Smith, *Electrical Vehicle Handbook.*

escape of the gas. The latter carries more or less of the acid electrolyte with it in the shape of a fine spray, and care should be taken to keep this spray from falling on the clothes or similar objects, as it causes ruinous stains, and only a comparatively small quantity is required to burn holes in cloth.

Temperature of Battery. When the battery is out of the vehicle, as in the case under consideration, the matter of temperature is not so important, but when it is in the vehicle, precautions must be taken to provide all possible ventilation. The charging causes a rise in the temperature of the cells and this should never be allowed to exceed 110° F. under any circumstances. The lower it can be kept the better, and a battery which is never allowed to exceed 90° F. while under charge will last much longer and give better service. The reason for this is to be found in the fact that the heating causes the active material in the grids to expand. If this expansion be excessive, as where the temperature is allowed to get too high, the material is apt to bulge completely out of the retaining pockets, so that it does not return when cooled off again. This destroys its

connection with the lead grid, cutting down its conductivity and greatly lowering the efficiency of the cell. Furthermore, after this bulging of the paste has occurred, there is the possibility at any time that flakes of active material will drop down below the plates and cause a short-circuit. Even if it does not cause this trouble, the accumulation of the material in the bottom may soon be enough to short-circuit the whole cell unless it is of the type provided with an especially deep space below the plates. The temperature should accordingly be noted from time to time during the charge and, if it passes safe limits, the charging rate must either be reduced or

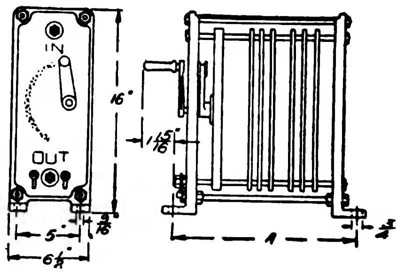

Fig. 57. Typical Battery-Charging Rheostat
Courtesy of General Electric Company, Schenectady, New York

discontinued altogether in order to give the cells an opportunity to cool off.

Experience has shown that the best results are obtainable from a storage battery when its temperature is maintained between 70° and 90° F. during both the charge and discharge. A considerably lower temperature will materially reduce the available charge of the battery, but this does not tend to injure it in any way, as a return to normal temperature restores its capacity. This is not true of a higher temperature, however, for if it is kept above normal for any length of time the wear on the plates is excessive.

Charging Rate. Every battery has a certain charging rate, and this should be taken from the chart sent with it by the manufacturer. It will be found that there are two rates—a starting rate and a finishing rate—and, as it is during the final part of a charge that the greatest wear falls on the battery plates, instructions regarding the strength of the current to be employed for starting and finishing the

charge should be closely followed. The more slowly a battery can be charged within reasonable limits, the better will be its condition at all times, and the longer its life. It is not always convenient, however, to give a battery as slow a charge as desirable in electric vehicle work. On the contrary, the car is often wanted at short notice not long after the battery has been discharged, and consequently it is abused by being charged at an injurious rate for a short period. Theoretically, 10 amperes for ten hours and 50 amperes for two hours are the same and should give a battery capacity of 100 ampere hours. But the "storing" of the current is purely a process of chemical conversion that cannot be accomplished at a rapid rate without injuring the plates.

Fig. 58. Typical Charging Rheostat

The manufacturer specifies that each type of cell shall be started at a certain charging rate, say, 10 amperes. The charging rheostat is manipulated until the ammeter shows that the amount of current in question is going into the batteries. Figs. 57 and 58 show two forms of charging rheostats. This rate is maintained until the voltmeter indicates that a certain potential has been reached, which is usually a voltage of about 2.55 volts per cell, measured with current flowing. The charging rate should then be reduced to 4 amperes, which causes a considerable drop in the battery voltage. This reduced charging rate is then maintained until the voltage again rises to the point at which the voltmeter stood when the current was reduced, i. e., until the voltage ceases to rise, which will generally be the same as the voltage at which the high rate of charge must be reduced. The

total voltage of the battery is usually taken as an indication, and when this fails to reach the desired figure, it is usually a symptom that some of the individual cells have defaulted. The remedy for this is given later.

Precautions. At the end of both the *starting* and *finishing* periods, the cells will be gassing freely, i.e., giving off large quantities of hydrogen, and for this reason the battery space of the vehicle should be open and the room in which the charging is done should be well ventilated. In addition to being highly inflammable and explosive, this gas is also very irritant to the throat and lungs and when present in any quantity causes constant coughing. Nothing but electric light should ever be employed in a private garage used for the charging of an electric car.

There are a number of other precautions to be observed when placing the battery on charge in the vehicle besides that of providing ample ventilation, as already mentioned. The controller handle should be locked in the off position, the lamps switched off, and the bell should not be rung during the progress of the charge. The reason for the first of these precautions is self-evident and for the latter two is found in the increased voltage during the charge, and particularly as it approaches completion. This would be sufficient to cause the lamps to burn out and to injure the bell. It is important that the manufacturer's directions with regard to the charging rate be closely observed. In order to be certain that this is done, the current should be measured by an accurate ammeter mounted on a panel board in the garage. The ammeter on the vehicle should never be employed for this purpose, as the vibration and road shocks to which it is subjected make the accuracy of such a delicate instrument a very uncertain quantity.

Starting the Charge. To start charging, the rheostat handle should be turned so as to throw all the resistance in. The switch on the panel board should be open, and the charging plug should then be inserted in its receptacle on the car. These plugs are usually made so that they can be inserted only in the proper way, and there is no danger of reversing the polarity of the current in this manner. Where not thus designated, the terminals are properly marked and care must be taken to see that the plug is correctly inserted. When the plug is in, the switch may be thrown on. Battery manufacturers

supply tables showing what the starting and finishing voltages of the battery should be, as well as its final voltage; but as this will be influenced by varying conditions, such as the temperature of the battery and the age of the plates, the figures given are only approximate. Furthermore, a new battery will have a higher final voltage than an old one under the same temperature conditions, and both old and new cells will read higher with the temperature low than when it is comparatively high. In view of the foregoing, a fixed voltage cannot be considered as an accurate test in determining the completion of the charge. Instead, a maximum voltage will be found the only certain indication. This may be determined by noting when the voltage ceases to rise as the end of the charge approaches.

When charging during the day, the progress of the charge should be noted at half-hour intervals, the current being cut off as soon as the voltage has stopped rising. *One of the commonest ways of abusing a battery is to overcharge it.* This is most often done under the impression that an increased mileage will result, doubtless on the theory that if a certain distance can be covered by the vehicle on a full battery, "cramming" it a bit should give as many more miles proportionately as the excess charge bears to the normal capacity. Needless to add, this is a fallacy. No additional mileage will result from excessive overcharging, and where this occurs it causes the plates to deteriorate and thus reduces instead of increases the distance that may be covered. A direct indication of excessive overcharge takes the form of a noticeable increase in the temperature of the cells.

The question of temperature during the charge has already been touched upon. This should not exceed 110° F., and when charging with the battery in the vehicle, as is usually done, the middle cells should be taken as a guide. Unless it cannot be avoided, it is preferable not to allow the cells to rise above 100° F., reducing the charging rate or stopping the charge altogether for a time if the temperature does reach this point.

Automatic Charge-Stopping Device. Where constant attendance during charging is neither practicable nor desirable—as in the case of the owner who takes care of his own car—an automatic charge-stopping device is a great convenience. This is an attach-

ment to the Sangamo ampere-hour meter, which is described in detail, page 158. It consists of a solenoid-actuated trip circuit breaker, Fig. 59, which is set in operation by the pointer of the meter when closing a circuit on arriving at the point of full charge, a point which has been fixed by the operator in advance. However, as it is necessary to put more current into a storage battery than can be taken out of it (see Fig. 11), a certain amount of overcharge must be allowed for in every case. The amount necessary will naturally depend upon the condition of the battery as influenced by its age and the treatment it has received, but it can be determined readily after a little experience. In the Sangamo differential shunt ampere-hour me ter referred to, a sliding adjustment is provided for this purpose and, once set, it need not be disturbed for a considerable period unless made necessary by a change in the condition of the battery. With this adjustment made, the charging can be done by any unskilled laborer, as it is only necessary to make the charging connection and leave it. Since the circuit cannot

Fig. 59. Solenoid-Actuated Trip Circuit Breaker
Courtesy of Sangamo Electric Company, Springfield, Illinois

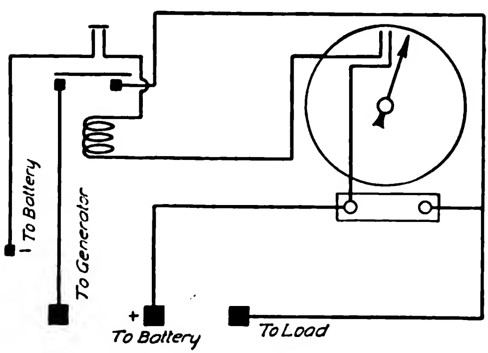

Fig. 60. Circuit Diagram of Charge-Stopping Device, Sangamo Ampere-Hour Meter

TABLE III

Temperature Correction for Specific Gravity of Electrolyte*

30° F.	40° F.	50° F.	60° F.	70° F.	80° F.	90° F.	100° F.
1.317	1.313	1.310	1.307	1.303	1.300	1.297	1.293
.12	.08	.05	.02	1.298	1.295	.92	.88
.07	.03	.00	1.297	.93	.90	.87	.83
.02	1.298	1.295	.92	.88	.85	.82	.78
1.297	.93	.90	.87	.83	.80	.77	.73
.92	.88	.85	.82	.78	.75	.72	.68
.87	.83	.80	.77	.73	.70	.67	.63
.82	.78	.75	.72	.68	.65	.62	.58
.77	.73	.70	.67	.63	.60	.57	.53
.72	.68	.65	.62	.58	.55	.52	.48
.67	.63	.60	.57	.53	.50	.47	.43
.62	.58	.55	.52	.48	.45	.42	.38
.57	.53	.50	.47	.43	.40	.37	.33
.52	.48	.45	.42	.38	.35	.32	.28
.47	.43	.40	.37	.33	.30	.27	.23
.42	.38	.35	.32	.28	.25	.22	.18
.37	.33	.30	.27	.23	.20	.17	.13
.32	.28	.25	.22	.18	.15	.12	.08
.27	.23	.20	.17	.13	.10	.07	1.203
.22	.18	.15	.12	.08	.05	1.202	.98
.17	.13	.10	.07	1.203	1.200	.97	.93
.12	.08	.05	1.202	.98	.95	.92	.88
.07	1.203	1.200	.97	.93	.90	.87	.83
1.202	.98	.95	.92	.88	.85	.82	.78
.97	.93	.90	.87	.83	.80	.77	.73
.92	.88	.85	.82	.78	.75	.72	.68
.87	.83	.80	.77	.73	.70	.67	.63
.82	.78	.75	.72	.68	.65	.62	.58
.77	.73	.70	.67	.63	.60	.57	.53
.72	.68	.65	.62	.58	.55	.52	.48
1.167	1.163	1.160	1.157	1.153	1.150	1.147	1.143

*Cushing and Smith, *Electric Vehicle Handbook.*

be broken until the predetermined number of ampere hours have been absorbed by the battery, the latter will remain connected to the mains until fully charged, so that there is no danger of either undercharging or overcharging, as may occur where the charge is simply limited by the time considered necessary. The circuit of this charge-stopping device is shown by the diagram, Fig. 60. The circuit breaker also opens the exciting circuit, so that it carries the current only for an instant.

Rated specific gravity for various stages of charge is based on a temperature of 80° F. Corrections for temperatures above and below this point may be made from Table III.

Testing Progress of Charge. Upon the completion of the charge, the rheostat handle should always be turned back before opening

the battery switch. It is essential that any voltage readings taken as a guide of the battery's condition should be noted only while the charging current is on. This applies likewise to readings during the discharge of the battery, which should be taken while the vehicle is running, as the voltage with the battery standing idle is of no value as an indication of its condition.

But the voltage alone must not be depended upon. The specific gravity of the electrolyte as well as the voltage will rise and reach a maximum as the end of the charge approaches. Specific gravity readings should therefore be taken with the hydrometer syringe provided for this purpose. This instrument consists of a glass syringe in which there is a hydrometer, Fig. 61. By inserting the point of the syringe in the venthole of a battery, it may be filled with the electrolyte, thus causing the hydrometer to float. The specific gravity of the solution may be noted and the latter replaced in the cell without any necessity for handling. Several cells in various parts of the battery should thus be tested as

Fig. 62. Syringe Hydrometer Set

Fig. 61. Acid Testing Set in Separate Parts

TABLE IV

Baumé Scale of Specific Gravities

Baume	Specific Gravity	Baume	Specific Gravity
0	1.000	18	1.141
1	1.006	19	1.150
2	1.014	20	1.160
3	1.021	21	1.169
4	1.028	22	1.178
5	1.035	23	1.188
6	1.043	24	1.198
7	1.050	25	1.208
8	1.058	26	1.218
9	1.066	27	1.228
10	1.074	28	1.239
11	1.082	29	1.250
12	1.090	30	1.260
13	1.098	31	1.271
14	1.106	32	1.283
15	1.115	33	1.294
16	1.124	34	1.306
17	1.132	35	1.318

a check of the voltage. Another form of testing set is shown in Fig. 62. When fully charged, the specific gravity of the electrolyte should be between 1.270 and 1.280. Because of the spraying through the ventholes when the cells are gassing freely, and the loss by sloppage and evaporation, there is a gradual lowering of the specific gravity. It may be permitted to run as low as 1.250 when fully charged. It is not necessary to make both the voltage and specific gravity tests every time the battery is charged, but they should be carried out at least once a fortnight, when all the cells should be tested to determine if they are in uniform condition.

Baumé Scale. Hydrometers are often graduated according to the Baumé scale. The Baumé scale for liquids heavier than water is based upon the following equation:

$$\text{Sp. Gr.} = \frac{145}{145 - \text{Baumé degrees}} \text{ at } 60^\circ \text{ F.}$$

Table IV gives the corresponding specific gravities and Baumé degrees.

Should the specific gravity of some of the cells be lower than the remainder of the battery, the low cells should first be charged separately at a low rate. If the specific gravity increases, it is an indication that the cell had been discharged to a lower point than the

others and simply needed additional charging. Should this not be the case, and if neither the specific gravity increases nor the temperature rises rapidly during the charge, it indicates that the gravity of the electrolyte has been lowered by the addition of water to compensate for loss due to leakage or similar cause. The cell should accordingly be examined for the cause of the loss by sawing through the connections or straps and removing the cell from the battery. If the jar is found to be broken or cracked, a new one should be substituted, new electrolyte of the same specific gravity as that of the remaining cells put in, and the cell fully charged. The specific gravity of the electrolyte should then correspond with that in the other cells. If the loss of electrolyte has been due merely to slopping over, electrolyte should be added and the whole tested for the right specific gravity. The outside of the jar and the tray beneath it should be thoroughly cleaned, and the cell put back and its connections burned into place, care of course being taken to have positive and negative plates connected as they were before removal.

As the electrolyte of the Edison cell does not vary with its state of charge, the specific gravity test cannot be employed, the voltmeter affording an accurate indication of the condition of the cells. Electrolyte cannot be lost from the Edison cell as it is sealed in, but there is a certain amount of loss by evaporation which must be replaced with distilled water.

Electrolyte. Manufacturers of storage batteries usually recommend that small users purchase their supplies of electrolyte from them in order to be certain of its purity and specific gravity. Where this is not convenient, the owner of the electric vehicle may mix his own solution. This should consist of *distilled water* and *pure sulphuric acid* in the proportion by volume of one part acid to four and three-quarter parts of water for electrolyte of 1.200 specific gravity, or one part acid to three of water for 1.275. A glass, porcelain, or earthenware vessel must be employed for mixing the solution, and the acid must be poured very slowly into the water. Never pour water into acid, for while the effect of slowly adding acid to water is negligible, the adding of water to concentrated acid is accompanied by violent chemical action and an evolution of heat will usually break the containing vessel and always cause a dangerous spattering of the acid.

The sulphuric acid should be chemically pure, and, wherever possible, distilled water should be used. If this is not obtainable, the use of clean rain water is recommended as being likely to contain less impurities than any other. The keeping of the electrolyte free from impurities is a matter of the utmost importance and one that must ever be borne in mind. All dirt and foreign substances, both liquid and solid, must be rigidly excluded. A piece of iron in the shape of a stray tack, small nut, or wire may fall into a cell and ruin it before its presence is discovered. The presence of iron will be indicated by the electrolyte and the positive plate becoming a dirty yellow color. Some other impurities also make their presence readily known, for instance, chlorine will give off fumes that are easily recognizable by their disagreeable odor.

Whenever such a condition is discovered, the only remedy is to dismantle the cell immediately, regardless of the state of charge or discharge it may be in. Discard the electrolyte and the wood separators, and thoroughly rinse in running water all parts of the cell, such as the jar, rubber separators, and both of the elements; the latter should be washed separately. Reassemble with new electrolyte of the same specific gravity as that discarded, and new wood separators. Charge the cell and discharge fully several times. After the last of these discharges and before recharging, take the cell apart a second time, again discarding the electrolyte, rinsing the parts of the cell in running water and soaking the wood separators in several changes of water. The cell may now be reassembled permanently with electrolyte of 1.200 specific gravity. It should be given a long charge before being put into service again. Care must be taken not to allow the negative elements to become dry at any time during this operation, in fact, it is better to keep both sets of plates under water until reassembled.

Dangers of Overcharging. To revert to the subject of charging in general, too much cannot be said regarding the evils of giving an excessive overcharge, an abuse which may occur in two ways: charging the battery for too long a time, and charging too frequently. The commoner of these—that of charging too long a time—is easy to avoid. The other is not so apparent, and is the result of a practice which is apt to be indulged in by the uninitiated owner of an electric car, being due to a desire to have it always ready to run

its available mileage. This is the custom of charging too frequently. For instance, if the capacity of the battery will run the car 40 miles on a charge, and but 5 miles are covered and a short charge given, then 10 miles are covered, and a second charge, followed by a second and third installment of 10 miles with a charge between each and after the last, it is obvious that but 35 miles have been covered altogether, but the battery has been charged four times. This is three times more than was necessary under the circumstances, besides which the available radius was not covered, so that the battery would really not have been discharged had the entire distance in question been covered without recharging. The greatest wear on the plates of a battery occurs during the final part of a charge, so that the oftener the battery is charged the shorter its life will be. As stated at the outset, the life of the very best cell made is measured by a certain number of discharges, but this is on the assumption that it is not recharged until actually discharged each time. Where a vehicle is employed for short runs, such as those mentioned, the capacity of the battery will not give as great a mileage as if the entire distance were covered in one run. When covering but a few miles in daily service, it is not advisable to recharge until between 50 and 75 per cent of its capacity has been exhausted.

Where it is desired to use the car within a comparatively short time after the battery has been exhausted, it is permissible to hurry the charge within certain limits by using a higher rate than normal. This should not exceed 50 per cent increase under any circumstances and should be employed only at the start of the charge. When the "finishing" voltage has been reached, the charge should be reduced to the normal starting charge, the remainder of the charge being carried out as if the battery had been started on the latter. Great injury may be done to the plates by "pounding" a nearly full battery at a high rate of charge. The foregoing precautions do not apply to the Edison cell.

Time Required to Charge. The time required for charging will naturally depend upon the extent of the preceding discharge. If the latter has been two-thirds of the rated capacity of the battery, the usual pleasure car will require about three hours at the starting rate and one and a half to two hours at the finishing rate. In other words,

about 10 to 15 per cent in excess of the amount discharged is usual. At least once a fortnight, a prolonged charge should be given by continuing the charge for one hour after the specific gravity of the electrolyte has ceased to rise. Where a vehicle is maintained by its owner in a small private garage, and is used more or less during the day, it will be found a great convenience to do most of the charging during the night, and for this purpose the mercury arc rectifier, described in the chapter on "Methods of Charging", will be found a great help. Where direct-current service is available at 110, 220, or 500 volts, such an adjunct will naturally not be necessary. In over-night charging, precautions must be observed to prevent an excessive overcharge. To do this, a careful estimate of the current required to fully charge the battery must be made before putting it on charge, and the rate adjusted accordingly. If 12 hours be available for charging and 84 ampere hours are necessary, the average rate of charge must be 7 amperes. Should the time be only 9 hours, as where a vehicle has been used in the evening and is wanted again early in the morning, the average rate would be slightly more than 9 amperes. Where 72 ampere hours are required in 9 hours, the rate would be 8 amperes, and so on. The rate, however, will also depend to some extent on the voltage of the charging circuit, in charging from a source with constant voltage, the rate into the battery will fall as the charge progresses. This is also the case where the charging is done with the aid of a mercury arc rectifier. After the charge is ended, the voltage will drop immediately when the battery is disconnected.

Charging an Edison Battery. The charging rates of Edison cells are based on a voltage of 1.85 volts per cell, so that the potential required to charge a battery of this type is as follows:

Number of Cells	Volts Across Cells
10	18.5
20	37.0
30	55.5
40	74.0
50	92.5
60	111.0
70	130.0
80	148.0
90	167.0
100	185.0

These voltages are just sufficient to charge the number of cells in question at the normal rate during the end of the charge, as the alkaline cell increases its voltage during charge in the same manner as the lead cell, there being also a similar drop in voltage when the charging current is shut off. While a slight reduction in voltage from the potentials given will not materially affect the charge, allowance should be made for what is required in every case, if necessary, by charging the battery in series multiple.

Owing to their construction the Edison cells are capable of being *boosted* at high rates when it is necessary to charge quickly, but the temperature must not be allowed to exceed 115° F. The following are the boosting rates recommended by the makers as the result of experience:

5 minutes at 5 times the normal rate
15 minutes at 4 times the normal rate
30 minutes at 3 times the normal rate
60 minutes at 2 times the normal rate

The sizes, capacities, charge and discharge rates of the Edison cells are as follows:

Type A-4	A-5	A-6	A-8	A-10	A-12
Capacity 150 ampere hours .	187.5	225	300	375	450
Normal charge, Normal discharge } 30.	37.5	45	60	75	90

They are capable of discharge rates in excess of these figures in the same proportion as the boosting rates.

BOOSTING

Advantages of Boosting. The term "boosting" as applied to electric-vehicle batteries may be defined as "auxiliary charging", and must not be confused with its use in connection with the charging of large stationary batteries. As the lead-plate cell becomes completely charged, its voltage rises to 2.5 volts per cell, which for the 55 cells required to deliver current at 110 volts, would mean a potential of 137.5 volts, or an increase of more than 20 per cent over that of the generator. The latter, not only being a constant potential dynamo, but also being called upon to deliver current for other service while charging the battery, it is necessary to raise the voltage

of the charging current in order that it may exceed that of the battery without, at the same time, altering the output of the generator. For this purpose, what is known as a "booster" is employed, i. e., a motor-generator which imposes a higher voltage on the charging current than that at which it is produced by the main generator.

In the case of a vehicle battery, it usually implies a partial charge given in a comparatively short time and at current rates considerably higher than normal, and it represents a practice which has had an important influence on the use of the electric vehicle for commercial purposes. For example, many of New York's several thousand electric trucks of three to five tons' capacity are now sent on trips that were considered beyond the range of the electric only a few years ago, as it is not unusual for five-ton brewery trucks to make a fifty-to-sixty-mile day's run in one round trip from the plant. How this is accomplished with batteries whose normal output only suffices to run the car forty miles on a charge will be apparent from a consideration of the practice of "boosting" the battery, which is usually carried out during the noon hour.

Fig. 63. Anderson Charging Regulator
Courtesy of Economy Electric Company, Economy, Pennsylvania

Regulation of Boosting Charge. Stress has already been laid on the fact that overcharging at high rates is injurious to the lead battery, and is the one thing to be most carefully avoided. However, the improved forms of vehicle batteries now in use have considerable ability to absorb current at high rates under proper conditions. The only factors which act injuriously in high-rate charging are *gassing* and *heating*, and these appear only when the battery is receiving more cur-

TABLE V

Potential Boosts at Different States of Discharge

Battery Charge	20-Minute Boost Increase	40-Minute Boost Increase	60-Minute Boost Increase
Battery fully discharged	22%	38%	50%
Battery three-quarters discharged	19%	33%	42%
Battery one-half discharged	15%	26%	32%
Battery one-quarter discharged	10%	16%	20%

rent than the plates can utilize. Therefore, any current rate which the cells will absorb without gassing is not injurious, and it is upon this principle that boosting is applied. As an automatic check upon the harmful rise of the temperature in a battery, the Anderson regulator, Fig. 63, has been devised. This is simply a thermostat designed to cut down the charging current by automatically inserting more resistance in the field of the generator when the temperature exceeds 100° F., the maximum temperature which a storage battery should ever be allowed to reach being 110° F. The device is inserted through the venthole of one of the cells, one of its terminals being connected to the battery and the other to the field coils of the generator. As the temperature rises, the circuit is closed and the field strength reduced until it drops again. It also acts as a check on the height of the electrolyte, as it will heat up in direct proportion as the solution is low.

Possible Safe Charging Rates. The more nearly discharged a battery is the higher charging rate it can take, and by starting the charge at a high rate and tapering to a low rate at the end, a large proportion of the discharge can be replaced in a very short time. Table V gives the additional battery capacity which can be obtained by constant potential boosts with the battery in different states of discharge.

Expressed in terms of mileage, this would mean that a car, after having given forty miles on a complete discharge, could have its battery boosted as follows:

In 20 minutes so as to give 9 miles additional
In 40 minutes so as to give 15 miles additional
In 60 minutes so as to give 20 miles additional

Thus, by charging during the noon hour, 140 per cent of the battery capacity is obtained in one day, bad weather conditions

particularly representing conditions under which it is advantageous to be able to boost the battery. A battery may have sufficient capacity to give the required mileage under normal conditions, but not when the roads are heavy, as after a storm, because the current consumption is then abnormally high.

Methods of Boosting. There are several methods by which boosting can be practically carried out, and the method chosen depends upon the available charging facilities.

Constant-Potential Method. The ordinary incandescent lighting circuit is supplied by a constant-potential generator, i.e., the voltage does not vary regardless of the current utilized within the limits of the capacity of the generator. Where conditions permit, this is the best method because it is entirely automatic and requires little attention. It is applicable wherever there is available a voltage of about 2.3 volts per cell of battery—say 110 volts for 48 cells—and the charging equipment and wiring have sufficient capacity to carry current up to four or five times the usual charging rate. A voltage higher than 2.3 volts per cell can be reduced by having a set of counter-e.m.f. cells figured at 3 volts per cell, which are always put in series with the battery when it is boosted. This is a special type of cell designed for this purpose. Thus if the line voltage is 110 and the battery consists of 40 cells, a reductioı of 18 volts will be necessary, and six of the counter-e.m.f. cells will be required.

With the charging voltage thus fixed at 2.3 volts per cell, a battery in any state of discharge can be put on charge and will receive in a short time a large proportion of the discharge which has been utilized. The current input will taper automatically from a high rate at the start to a low rate at the finish, and no attention or adjustment is required. The cells will not reach the *free gassing* point or, under normal conditions, a high temperature and, therefore, no harm will result from their being inadvertently left on charge.

Approximate Constant-Potential Method. This is employed with a fixed resistance in series with the battery; and when the time available for boosting is one hour or less, the following method is often the simplest. Connect a rheostat in series with the battery and adjust the resistance so that the voltage across the *battery terminals* corresponds to that given as follows for the approximate number of cells.

Number of Cells	Voltage at Battery Terminals
48	110
44	98
42	92
40	86
38	80

The circuit can then be left without attention for an hour or so, and the current will taper off as the voltage of the battery rises. The table is figured for a line voltage of $\frac{110}{120}$, and the voltages given are too high for a boost of more than one hour's duration.

Constant-Current Method. In some cases it is more convenient to boost at a constant rate of current, and, as there is usually a limited time available, it is desirable to know under any given conditions what rate is safe. This may easily be determined as follows:

$$\text{Charging current (amperes)} = \frac{\text{ampere hours already discharged}}{1 + (\text{hours available for boosting})}$$

This gives the maximum current which can be employed for the time specified without the cells reaching the gassing point. The method is most conveniently employed where the car is equipped with an ampere-hour meter. For example, 100 ampere hours have been discharged and there is one hour available for boosting. Then

$$\text{Charging current} = \frac{100}{1+1} = 50 \text{ amperes}$$

In general, this method will not put in as much charge in a given time as the constant-potential method, and the current must not be continued *beyond the time for which the rate is figured,* as injurious gassing and heating will result. When a considerable period is available for boosting, and it is convenient to regulate the current at intervals, a greater amount of charge is possible by dividing the time into several periods and regulating the amount of current for each period separately. It will usually be found that one of the methods outlined will be available, but to obtain the advantages of boosting without injury to the battery, gassing must be avoided and the temperature of the cells kept below 110° F.

Table VI is based upon the above formula and saves the necessity of making calculations.

TABLE VI

Boosting Rates*

Ampere Hours Discharged	Time Available for Boosting							
	¼ hour	½ hour	¾ hour	1 hour	1¼ hours	1½ hours	1¾ hours	2 hours
	Amperes	Amperes	Amperes	Amperes	Amperes	Amperes	Amperes	Amperes
10	8	6	5	5	4	4	3	3
20	16	13	11	10	9	8	7	6
30	24	20	17	15	13	12	11	10
40	32	26	23	20	18	16	14	13
50	40	33	28	25	22	20	18	16
60	48	40	34	30	26	24	22	20
70	56	46	40	35	31	28	25	23
80	64	53	45	40	35	32	29	27
90	72	60	51	45	40	36	33	30
100	80	66	57	50	44	40	36	33
110	88	73	63	55	49	44	40	37
120	96	80	68	60	53	48	43	40
130	104	87	74	65	58	52	47	43
140	112	93	80	70	62	56	51	47
150	120	100	86	75	67	60	54	50
160	128	106	91	80	71	64	58	53
170	136	113	97	85	75	68	62	57
180	144	120	103	90	80	72	65	60
190	152	127	108	95	84	76	69	63
200	160	133	114	100	89	80	73	67
210	168	140	120	105	93	84	76	70
220	176	147	126	110	98	88	80	73
230	184	153	131	115	102	92	84	77
240	192	160	137	120	106	96	87	80
250	200	167	143	125	111	100	91	83

*Courtesy of Electric Storage Battery Company.

EXPLANATION. In the left-hand column find the figure nearest to the ampere hours discharged from the battery; follow across to the column headed by the available time. The figure at this intersection is the current to be used.

EXAMPLE. Ampere-hour meter reading, 103 ampere hours discharged; time available for boosting, one hour. Start at 100 in the left-hand column; follow across to the column headed 1 hour and find 50, which is the current to be used.

CARE OF BATTERY

Importance of Careful Attention to Battery. While it would appear that the remainder of the car calls for no little attention, the amount, exclusive of that which must be given the battery, is very slight as compared with that necessary to maintain either a gasoline or steam automobile. The battery is naturally the chief factor in any electric automobile and, as its initial cost is no small fraction of

the total cost of the vehicle, its proper maintenance is a matter of economy no less than of good service. More so than any other piece of electrical apparatus, a storage battery has a definitely determined life. Regardless of the care given it, the active period of service of which it is capable may be expressed as a certain number of discharges. By properly looking after it, this number may be realized, and a greater percentage of the energy put into it taken advantage of. In other words, its life will not only be longer, but its efficiency much higher during that period as the result of proper care. It is difficult to impress upon the uninitiated owner the importance of paying strict attention to the letter of instructions concerning the care of the storage battery in a vehicle, and this accounts to a greater or less extent for those cases of dissatisfaction with the electric vehicle which occasionally come up. For the particular service for which it is designed, the electric vehicle has no superior, but its advantages are only to be enjoyed to the greatest degree by giving it regular and proper attention, and fully 90 per cent of this attention must be devoted to the battery.

It must be borne in mind that the storage battery in an electric vehicle must work under conditions which are diametrically opposed to those which make for high efficiency in such a piece of apparatus, for it is always subject to the destructive effects of vibration and jolting. To secure that degree of conductivity which is essential to high capacity, the active material should be loose and porous, but in order to fit it for vehicle service the plates must be made rigid and unyielding. For the same purpose, an ample quantity of electrolyte, so disposed as to permit of rapid circulation, should be employed, but the necessity of not only keeping the plates apart, but also of preventing any movement whatever, compels the use of separators which occupy space that should be given to the solution. The need for compactness is also against the latter. These conflicting requirements are pointed out here merely as an indication of the difficulties that must be met. The aim of storage-battery manufacturers has been to meet vehicle conditions, without impairing the electrical efficiency of the battery any more than has been absolutely necessary.

Limits of Discharge. To obtain the best possible service from a battery, it should never be discharged below 1.70 volts per cell,

or 41 volts for a 24-cell battery, this being measured when the vehicle is running at full speed on the level, all of the cells then being connected in series. If the average discharge rate is for any reason considerably more than the normal rate of the battery, the working voltage will be correspondingly lowered, so that a slightly lower limiting voltage is permissible. In general, however, it is safer not to go below 1.70 volts per cell, except momentarily, as when starting or on a grade. The battery should never be allowed to stand fully discharged, as local action and sulphating rapidly take place.

Sulphating. It has been pointed out in the introductory section of Part I that during each discharge both the positive and negative plates become covered with lead sulphate, but in the normal use of the battery the sulphate is converted during the following charge to lead peroxide on the positive plate and spongy metallic lead on the negative. Should the battery be allowed to stand in a discharged state for any length of time, however, the lead sulphate on the plates will harden, causing what is usually termed "sulphating". When the battery is put into use again this will result in loss of capacity, buckling, shedding of the active material from the positives, and greater heating of the cells due to increased internal resistance. Sulphating can be remedied by continuous charging for a long period at a low rate, i.e., for 24 to 36 hours, or longer, at a rate not exceeding 10 to 15 per cent of normal. This loosens the sulphate and reconverts it as previously mentioned, thus restoring the plates to their normal condition. The length of time and the charging rate necessary to effect a complete restoration will be governed by the extent to which sulphating has taken place, and the loss of capacity will afford a fairly approximate indication of this. The great loss of capacity, with the possible total ruin of the battery if allowed to go on long enough, explains the emphasis laid on the instructions—*never let the lead-plate battery stand discharged.*

When it is not convenient to have the battery fully charged at once, a partial charge should be given and completed as soon thereafter as possible, and before the battery is again discharged. When the vehicle is out of service, the battery should be given a freshening charge at least every month, and every two weeks would be preferable. A cell standing idle tends to discharge itself, owing to the unstable nature of the chemical compounds which represent the

stored energy; and if left in a discharged condition for any length of time, the cell will deteriorate far more than in the most active service under proper conditions.

As an additional indication of the relative condition of the cells in a battery, the voltage of each cell should be taken with a low-reading voltmeter—i. e., one calibrated to read to 3 volts by tenths—at least once every two weeks, and the specific gravity of the electrolyte of each cell should also be tested at about the same interval. The voltage readings in question should be taken just before the end of the prolonged charge mentioned, or just before the end of a complete discharge, and always with the current flowing. Should any of the cells read lower than the average, it is an indication of trouble and they should be treated as explained later.

Condition of the Cells. *Electrolyte.* One of the cardinal points to be observed in the care of the battery is to keep the plates covered with electrolyte to the depth of at least half an inch, but no more. Except where the level has been lowered by slopping or leaking, any loss should be replaced by the addition of distilled water. The water, being the more volatile part of the solution, is subject to evaporation, particularly on account of the increase in temperature due to the charge. The loss by evaporation causes a rise in the specific gravity, which would not be remedied by the addition of electrolyte. The latter is only necessary where the loss has been that of the solution itself, as from slopping or leakage. Water to replace evaporation should always be added at the beginning of a charge.

As it is not always convenient to obtain distilled water and as neither rain water nor melted artificial ice is available when wanted, a small gas-heated still has been placed on the market for this purpose. This is known as the "Peerless" water still, and is made in two or three sizes adapted to the use of private and public garages. It consists of a Bunsen burner for gas, an evaporating chamber directly over it in the form of a cowl, and a condensing tube which is cooled by passing the cold feed water around it. The smallest size has a capacity of one-half to one gallon of distilled water per hour and, once adjusted, will operate continuously without further attention. It is designed to be fastened to the wall in any convenient location, and only requires connecting with the gas- and water-supply pipes to put it in operation.

Connections. Attention should be paid to keeping the connections and terminals, the outside of the jars, the straps, battery trays, and the battery space in the vehicle dry and free from dirt and acid. This is a far more important precaution than may appear at first sight, for if not attended to, corrosion and loss of capacity will result. In storage batteries for starting and lighting gasoline cars, this difficulty has been obviated to a considerable extent by the use of a special form of cover incorporating an expansion chamber.

CLEANING OR WASHING A BATTERY

Methods of Avoiding Injurious Effect of Sediment in Cells. During the normal use of a battery, the gradual wear of the plates results in a deposit of sediment which collects in the bottom of the jar where a space is provided to hold a considerable quantity before it accumulates sufficiently to touch the bottom of the plates, Fig. 64. The rate at which sediment accumulates depends very largely upon whether the battery is charged properly or not. If the battery is charged in such a way as to cause excessive gassing, the gas coming out of the pores of the positive plates tends to soften and dislodge the active material. This is the reason the charging current must be reduced as soon as the cells begin to gas freely. If a battery is constantly undercharged, the sulphate which is thus allowed to accumulate in the negative plates will eventually lose its cohesion and the surface will gradually wash

Fig. 64. Elba Cell with Low Mud Space and Bolted Connections

away, falling to the bottom of the jar as a deposit of sediment. It is neither necessary nor desirable that every charge be carried to completion, but in order to make certain that the plates do not become sulphated, a weekly "equalizing" charge is given.

If a battery has been neglected so that cleaning is not undertaken until the deposit of sediment has actually reached the plates, the sediment is then deposited much more rapidly. Permanent injury and decreased life of the plates result. The Elba cell, Fig. 65, is designed with a mud space sufficiently high to accommodate the entire deposit of sediment occurring during the life of the elements, so that washing is not necessary in this type of cell, the jars only being cleaned out when the elements are renewed.

Fig. 65. Elba Cell with High Mud Space

Since the conditions under which batteries are operated vary so widely, the best method of determining when it will be necessary to clean a battery is to remove the element from one of the cells after about 100 to 150 charges have been given it, to determine the rate at which the sediment is accumulating. From the amount of sediment compared with the depth of the space in the bottom of the jar, it is possible to estimate when cleaning will be required. *Always clean a battery before there is any possibility of the sediment reaching the bottoms of the plates.* To insure this, the entire depth of the space should not be taken as a fixed quantity in estimating the rate of sediment deposit, but a margin of safety of ½ to ¾ inch should be allowed, since the jolting of the vehicle is apt to bring the sediment in

contact with the plates and short-circuit them momentarily, if allowed to rise any closer. At the expiration of the estimated time, cut out a different cell and examine it to determine definitely if the time for cleaning has arrived.

Various Conditions to be Found. The method of procedure in cleaning will depend upon the condition of the battery, as follows:

1. If the battery has not been allowed to become sulphated and the sediment has not reached the bottoms of the plates, its cleaning is a comparatively simple operation and the only preliminary treatment is to first bring the battery to a state of full charge.
2. If the battery is in a sulphated condition due to improper charging, but the sediment has not reached the bottoms of the plates, it should be given the treatment detailed under "Restoring a Sulphated Battery", before cleaning.
3. If the sediment has been allowed to reach the bottoms of the plates because cleaning was not carried out soon enough, the battery will, as a matter of course, be in a sulphated condition by reason of the short-circuits through the sediment. Such a battery must first be cleaned as described below and afterward given the treatment referred to under "Restoring a Sulphated Battery". This treatment cannot be given successfully in its short-circuited condition.

Materials to Have on Hand. Before starting the work of cleaning the battery, have on hand a set of new wood separators and sufficient new acid of 1.300 specific gravity with which to mix new electrolyte. Many of the old rubber separators can be used again, but, as is the case when renewing the entire element of the cell, about twenty-five per cent of new rubber separators should be at hand for replacements. Three or four extra jars and covers should also be at hand, and the trays should be examined to note if their condition is such that they may be depended upon to last the remaining life of the cells. If new trays are necessary, see instructions under "Renewal".

In fact, as the process of cleaning is, to a large extent, the same as that of renewing the elements, the instructions for dismantling the battery are the same. All the connectors should be removed by pulling or drilling. The jar covers should be lifted by running a hot putty knife around their edges, and the covers should be washed in hot water and then stacked one on top of the other with a heavy weight on them to press them flat.

Treating the Plates. Lift all the jars out of the trays, leaving their elements in the electrolyte. The trays can then be examined, and, if usable, given the treatment described in connection with renewals to neutralize any acid in the wood. Proceeding further,

one cell should be treated at a time. The element is pulled out with the aid of pliers, meanwhile holding the jar with the feet; it is laid on the bench and the plates spread slightly to permit of removing the separators, taking care not to injure the rubber sheets, Fig. 66. Separate the positive group from the negative. If the active material of the negative be swollen beyond the surface of the grid, press it back into position before it has a chance to dry by placing boards of suitable thickness between the plates and carefully squeezing the group between heavy boards in a vise or press, as shown in Fig. 67. Boards of sufficient size and thickness must be used between the plates or

Fig. 66. Removing Old Separators from Elements

Fig. 67. Pressing Negative Group

Courtesy of Electric Storage Battery Company, Philadelphia, Pennsylvania

breakage will result. Charged negative plates, when exposed to the air, will become hot in a short time and in this event should be allowed to cool before reassembling. Remove any loose particles adhering to the positive plates by passing a smooth wooden paddle over the surface, *but do not wash the positive plates.*

Washing or Renewing Separators and Assembling Cells. Wash all the sediment out of the jar to have it ready for the element when reassembled. Wash and save the rubber sheets, but throw away the old wood separators. "Wash" in this connection means to place under running water that is known not to contain any injurious impurities, for fifteen minutes or more. Reassemble the positive

and negative groups with the plates on edge in order to insert the separators. Place a rubber separator against the grooved side of a wood separator, Fig. 68, and insert a positive plate near the center of the element. The rubber sheet must be against the positive plate and the wood separator against the negative plate. In this manner, insert separators in all the spaces, working in both directions from the center, exactly the same as in renewing the element. An omitted separator means a short-circuited cell.

The separators should be practically flush with the bottoms of the plates to bring their tops against the hold-down below the strap, and must extend to, or beyond, the side edges of the plates. Grip the element near the bottom to prevent the plates from flaring out while placing in the jar. Fill the cell to within ½ inch of the top of the jar, using electrolyte of a specific gravity of 1.250, unless the battery is in a sulphated condition, in which case, use water. After all of the cells have been given the same treatment and reassembled, place them in the trays in the proper position, so that the *positive of each will be connected to the negative of the adjoining cell*, and connect temporarily by pressing the old connectors into position.

Fig. 68. Wood and Rubber Separator

Charging Process after Washing Battery. Put the battery on charge at the regular finishing rate and, after charging about fifteen minutes, note the voltage of each cell, recording these readings as mentioned in connection with renewals. This is to insure the cells having been correctly connected with regard to their polarity. If this is the case, each cell should read above 2 volts; any cell with a lower reading is likely to have been connected backward. When the cells begin to gas freely and uniformly, take and record a hydrometer reading of each cell and the temperature of one cell. Reduce the current to one-half the normal finishing

rate. Should the temperature reach 100° F., reduce the charge or interrupt it temporarily so as to prevent the cells getting any hotter. Both hydrometer and temperature readings must be taken at regular intervals, say four to six hours apart, to determine if the specific gravity is still rising or if it has reached its maximum. Continue the charge and the readings until there has been no further rise in any cell during a period of at least twelve hours. Maintain the height of the electrolyte constant by adding water after each reading. (If water were added just before taking the reading, it would not have time to mix with the electrolyte, and the reading would be misleading.)

Should the specific gravity rise above 1.300 in any cell, draw off its electrolyte down to the level of the top of the plates and refill with as much water as possible without overflowing. Continue the charge, and if the specific gravity again exceeds 1.300 all the electrolyte in that cell should be dumped out and replaced with water, then continue the charge. The charge can be considered complete only when there has been no rise in the gravity of any cell during a period of at least twelve hours of continuous charging. Upon completion of the charge, the specific gravity should be adjusted to its proper value (1.270 to 1.280), using water or 1.300 acid as may be necessary, and the electrolyte level adjusted to a uniform height of ½ inch above the plates.

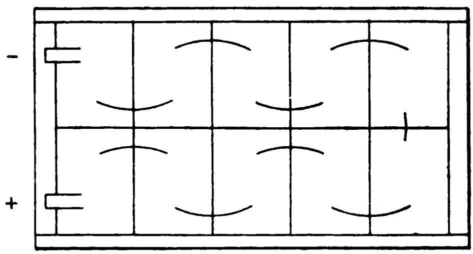

Fig. 69. Diagram of Battery Connections Drawn before Dismounting

Discharge the battery at its normal discharge rate (see "Renewal") to determine if there are any low cells caused by defective assembly, which should immediately be corrected. Recharge and then remove the temporary connectors. When the cells are arranged in their trays, as shown in the sketch made before the battery was taken apart, Fig. 69, put the rubber covers in place, wipe the inside edges of the jars dry, and seal with the compound supplied for this purpose. Heat the sealing compound, taking care that it is not allowed to burn, and apply around the edges of the cover, smoothing down with a hot putty knife.

It is preferable to use new connectors, but if these have not been provided, the old ones may be replaced if sufficient care has been taken in removing them. Before putting the connectors in place, scrape the posts clean and smooth. In using old connectors, clean out the eyes with a knife blade. When the connectors have been put in place, tap them down firmly to insure good contact. Before reburning the connectors in place, test each cell with a low-reading voltmeter to make certain that the cells have all been reconnected in the proper direction, i.e., that their polarity has not been reversed. It is not sufficient to note that the voltage of the cell is correct, i.e., 2 volts or over; but care must be taken also to note that it is in the right direction. With a voltmeter having a needle that can move in both directions from zero, one polarity will be evidenced by the needle moving over the scale to the right of the neutral line, while if the polarity be reversed, the needle will move to the left, so that a cell having the proper polarity should be tested, and then, to be correct, all the remaining cells should cause the needle to move in the same direction and read to approximately the same voltage when the instrument leads are held to the cell terminals in the same way for each. Where the voltmeter needle can move only in one direction, i.e., to the right, a change of polarity will be indicated by the needle of the instrument attempting to move to the left and, in so doing, butting up against the stop provided to prevent this.

Complete the reassembly of the battery by burning the connectors of all the cells together, detailed instructions for this being given under "Lead Burning". The cleaning of a battery which has been properly charged and in which the sediment has not been allowed to reach the bottoms of the plates is a simple operation compared with treatment necessary to clean and restore a battery which has been neglected. The process of cleaning is also frequently referred to as "washing the battery", which refers to the internal treatment already outlined, and not to washing it outside.

It is of the utmost importance that the battery be cleaned before the sediment is allowed to accumulate to a point where it reaches the plates.

Replacing a Defective Jar. When a cell requires the addition of distilled water more frequently than the other cells in the same battery, or does not test to the same specific gravity as the others, it is usually an indication that there is a leak in the jar. Failure to give

Fig. 70. Drilling off Connectors
Courtesy of Electric Storage Battery Company, Philadelphia, Pennsylvania

Fig. 71. Lifting Cell out of Tray
Courtesy of Electric Storage Battery Company, Philadelphia, Pennsylvania

the same gravity reading is not always proof of this condition, as the cell may be low from other causes, but the loss of electrolyte is certain evidence of it. The only remedy is to replace the jar at fault. While the following directions for doing this apply to the Exide battery in particular, they will be found equally applicable to all other makes.

After locating the jar at fault, first mark its connectors so that there will be no mistake in replacing them the same way. With a $\frac{5}{8}$-inch bit or twist drill of the same size, drill the connectors centrally in the top of the enlarged ends joined to the two cells adjacent to the jar that is to be replaced, Fig. 70. Lift the complete cell out of the tray, Fig. 71, and with an ordinary gasoline blow torch warm the sides of the jar around the top to soften the sealing compound that holds the cover, Fig. 72. Grip the jar between the feet, take hold of the two connectors, and pull the element almost out of the jar, Fig. 73; then grip the element near the bottom in order to keep the plates from flaring out, Fig. 74, while transferring to the new jar, taking care not to let the outside plates start down over the outside of the jar, Fig. 75. After the element is in the new jar, reseal the cell by pressing the sealing compound into place with a hot knife. Fill the cell with 1.250 electrolyte to the proper point, the old electrolyte being discarded.

Fig. 72. Softening Sealing Compound on Cell

Before replacing the connector, clean both the post and the inside of the eye of the connector by scraping smooth with a knife. When the connector has been placed in position, tap it down firmly over the post to insure good contact. To complete the connection, melt the lead of the connector and the post at the top so that they will run together, and, while the lead is still molten, melt in more lead until the eye of the connector is filled, Fig. 76. This is termed *lead burning* and is described at greater length in a succeeding section. Where no special facilities are at hand for carrying it out, it may be done with an ordinary soldering copper. The latter is brought to a red heat so that all the "tinning" is burned off and no flux of any kind is used.

Fig. 73. Lifting Element out of Jar by Hand

Fig. 74. Gripping Element near Bottom to Keep Plates from Flaring out

Fig. 75. Installing Element in Jars

Courtesy of Electric Storage Battery Company, Philadelphia, Pennsylvania

The method of handling the iron and the lead-burning strip to supply the extra metal required to fill the eye is shown in Fig. 77.

Put the battery no charge, and when the cells begin to gas freely, reduce the current to half the "finishing" rate given on the battery name plate, and

Fig. 76. Reburning Cell with Carbon Arc

Courtesy of Electric Storage Battery Company, Philadelphia, Pennsylvania

charge at this rate as long as there is any rise in gravity in the electrolyte in this or in any of the other cells. The maximum gravity has been reached when there has been no rise for a period of three hours. If the gravity of the cell having the new jar is then over 1.280, draw off some of the electrolyte and replace with

Fig. 77. Reburning Cell with Soldering Iron After Replacements Previously Described Have Been Made
Courtesy of Electric Storage Battery Company, Philadelphia, Pennsylvania

distilled water. If the gravity is below 1.270, draw off some of the electrolyte and replace with 1.300 electrolyte. If necessary to put in 1.300 electrolyte, allow the battery to continue charging for about one-half hour longer at a rate sufficient to cause gassing, which will cause the stronger acid to become thoroughly mixed with the rest of the electrolyte in the cell.

COMPLETE RENEWAL OF BATTERY

Materials Needed. In garages caring for a number of electric vehicles, it is customary to carry out all the repair work demanded by the batteries, including the complete renewal of the cells. The

material is ordered from the maker of the battery, and the form in which it is sent for will depend upon the facilities at hand. The following material is required for a complete renewal: positive groups, i.e., plates already burned to straps, or positive plates and positive straps, negative groups or negative plates and negative straps, connectors, burning strip, wood separators, rubber separators, rubber jars, rubber covers, rubber plugs, sealing compound, electrolyte, trays, handles, and terminals.

Note the number of plates and their size and type, this information usually being given on the plate on the tray. Unless facilities are at hand for burning the plates into groups, it is better to order groups. If the plates are ordered loose, positive and negative straps must also be ordered, and, in any case, the following information must be given: size and type of plate, number of plates per cell, length of jar outside, width of jar outside, height of jar outside, height from top of rib of jar. In ordering connectors, give the distance between the center of the eyes, noting if more information than the size is required. Two pounds of burning strip is sufficient for burning the connectors of an ordinary battery; when loose plates are ordered, provide one pound additional for each fifty plates. The clippings from the plate lugs can be melted down and cast into strips for this purpose, if desired.

Where the separator type cannot be identified by name or number, send samples of the old ones to the manufacturer. All new wood separators will be necessary, and in ordering these it is advisable to provide at least 10 per cent more than are actually required. Most of the old rubber separators can be used again, but it is well to provide about 25 per cent of new ones. Order three or four extra jars and covers, giving the dimensions as already noted. A new set of rubber plugs will usually be found advisable. The average pleasure-car battery or that of a light truck requires about $\frac{1}{8}$ pound of sealing compound per cell; this compound is supplied in 5-, 10-, and 30-pound tins. In dismantling the old battery, measure the amount of electrolyte necessary in one cell to bring its level $\frac{1}{2}$ inch over the plates, and order sufficient 1.300 electrolyte to fill all the cells. Electrolyte is usually longer in transit than any other material, so this must be allowed for. In ordering new trays, make a sketch showing the inside and outside length, width, and depth, and whether the sides

are solid or slatted, also specify the size and type of handles and their position. When obtained locally, trays should be well painted with an acid-resisting paint. Upon receipt of the material, immediate attention must be given the wood separators to prevent their drying out. *Wood separators must always be kept wet.*

Dismantling the Battery. To dismantle the old battery that is to be renewed, first remove all the connectors by drilling centrally in the top of the enlarged ends, as already explained in connection with the replacement of a jar. Where much of this work is done, a device termed a "connector puller" may be obtained from the battery maker. After removing the connectors, lift all the covers by running a hot putty knife around the sealed edges and, after they have been taken out, clean all the compound off them and place them in hot water. This will clean the acid from the covers and also soften them. In this condition, stack the covers and place a weight on them to keep them flat.

Lift all of the cells out of the trays. When making a complete renewal, the old trays are seldom worth saving, but if they are to be used again, immerse them in a barrel of water in which about 10 pounds of bicarbonate of soda (common baking soda) has been dissolved, to neutralize the acid in the wood. After drying, they will be ready for use. Grip one jar firmly between the feet and lift out the element with the aid of two pairs of pliers, Fig. 78. Spread the plates slightly and remove the wood and rubber separators, taking care not to injure the rubber sheets. Throw away the old wood separators and scrap the old plates. Wash all sediment out of the jars to have them ready for assembling the new elements.

Fig. 78. Lifting Element out of Jar with Pliers

Burning Groups. When new plates and straps have been ordered separately and are to be burned into groups, first provide a "burning box", as shown in Fig. 79. Scrape the plate lugs clean and bright and arrange the plates as shown in the burning box. The height of this box should be $\frac{7}{8}$ inch less than the distance from the top of the ribs of the rubber jar to the top of the jar. The burning iron, which acts as a space between the plates and as a support for the strap, should be made of iron $\frac{1}{8}$ inch thick and slotted to fit the plate lugs. This $\frac{1}{8}$ inch in addition to the height of the burning box will give the right height for the strap, the bottom of which should be $\frac{3}{4}$ inch below the top of the jar.

Fig. 79. Assembling Group in Burning Box

Place the strap over the plate lugs to rest on the burning iron. The plate lugs should be trimmed about flush with the top of the strap. After burning, cut off the projecting ends of the negative straps so that the elements may enter the jars, Fig. 80. It is not necessary to clip off the ends of the positive straps.

Before dismantling the old battery, a sketch of the position and polarity of the cells in each tray should be made, indicating the position of the tray terminals and their polarity, that is, whether the positive is to the right or left side of the tray when facing the terminal end, Fig. 69.

Fig. 80. Clipping off End of Negative Strap

Reassembling the Cells. Assemble the new positive and negative groups with the plates on edge in order to insert the separators.

Place a rubber separator against the grooved side of a wood separator, Fig. 68, and insert between a positive and a negative plate near the center of the element. The rubber sheet must be against the positive and the smooth side of the wood separator against the negative, Fig. 81. In like manner, insert separators *in all the spaces,* working in both directions from the center. *Leaving out a separator means a short-circuited cell.* The separators should be practically flush with the bottom of the plates to bring their tops against the hold-down below the strap and must extend to or beyond the side edges of the plates. Grip the element near the bottom in order to prevent the plates from flaring out when placing the element in the jar.

Fill the cells to within ½ inch of the top of the jars, using electrolyte of a specific gravity of 1.300 and allow the cells to stand from

Fig. 81. Installing Separators
Courtesy of Electric Storage Battery Company, Philadelphia, Pennsylvania

twelve to twenty-four hours before starting to charge. After all the cells have been assembled, place them in trays in the proper position, so that the positive of each will be connected to the negative of the adjoining cell and connect temporarily by pressing the connectors into position by hand, using the old ones if available.

Initial Charge. Give the initial charge by putting the battery on the regular finishing charge rate. After charging about thirty minutes, note the voltage of each cell, recording these readings as shown in the first column of the form, Fig. 82.

This is to insure that all the cells have been properly connected up, i.e., in the direction as to polarity. If they have been properly

connected, each cell will show in excess of 2 volts. Any cell showing less than 2 volts is probably connected backward and should be inspected. Then reduce the charging current to as near one-half of the regular finishing rate as the charging apparatus will permit. Select one cell near the center of the battery, which will be the

Pilot cell to be inside cell near center of battery. Specific gravity readings taken every six (6) hours at proper hour in first column and to continue into following columns to end of charge.

Electrolyte in pilot cell to be kept at uniform height at one-half inch above plates by addition of distilled water only. Water to be added just after taking readings.

Any additional readings wanted can be put in blank columns, proper headings being filled in.

This sheet must be COMPLETELY FILLED OUT, nothing asked for being omitted.

Discharge following this charge to be recorded on back of this sheet

BATTERY FILLED WITH 1200 Sp. Gr. 5.00 P.M. Jan. 3 1914

BATTERY on charge FROM 7:20 A.M. Jan 4 1914 TO 11:30 P.M. Jan 14 1914

Pilot Cell No. 16

Fig. 82. Specimen Battery Charging Record
Courtesy of Electric Storage Battery Company, Philadelphia, Pennsylvania

"pilot cell" throughout the charge. Record readings of time and current and the specific gravity and temperature of this pilot cell, as indicated in the lower form, Fig. 82, at intervals of from six to twelve hours. Should the temperature at any time reach 100° F., reduce the current or temporarily interrupt the charge so as not to exceed this temperature.

Maintain the level of the electrolyte by adding water as necessary. Never add water just before taking hydrometer readings because it would not have time to mix with the electrolyte and would give a misleading reading. Hydrometer readings should be corrected for any substantial change in the temperature, as detailed in the section on the Use of the Hydrometer, Part I. When the gravity of the pilot cell has shown no further rise for a period of twenty-four hours, record hydrometer readings of each cell in the column marked "specific gravity", Fig. 82. In recording readings, start at the positive terminal of cell No. 1, and follow the direction of the electric circuit. Individual cell readings should be recorded at intervals of about twelve hours *to insure that each reaches a maximum.* Bear in mind that the object of the initial charge is to remove all acid combined in the plates.

Do not stop the initial charge just because a specific gravity of 1.270 or 1.280 may have been reached, because this may not be the maximum. Continue to charge as long as the gravity continues to rise. The charge can be considered complete only when there has been *no rise in the gravity of any cell during a period of twenty-four hours of continuous charging.* In case the gravity rises about 1.290 in any cell, draw off its electrolyte down to the top of the plates and replace with water, saving this electrolyte for adjusting the specific gravity of the cells as follows: Upon completion of the charge adjust the specific gravity to its proper value (1.270 to 1.280), using water or electrolyte as may be required, and bring the level of the electrolyte to a uniform height of ½ inch above the tops of the plates. Some variation on the specific gravity among different cells is to be expected, since the amount of water in the separators and difference in level when filled affect this.

Importance of Initial Charge. The foregoing outline of procedure is based on the assumption that the initial charge is continuous, since this will require the shortest time. It is especially desirable that the first twenty-four hours of the charge be given without interruption, even if the entire charge cannot be made continuous. Where there are interruptions, the twenty-four hours of maximum gravity must be actual charging time and must not include any idle time. The accuracy of the ammeter should be checked for the current readings used.

A battery which has not received sufficient initial charge cannot be expected to give satisfactory service and life. Therefore, in case of any doubt, prolong the charge rather than run the chance of stopping it too soon. As a further precaution, it is advisable to see that the first few charges after the battery goes into service are somewhat prolonged.

Test Discharge. After giving the battery its initial charge, it is customary to make a test discharge and, if necessary, recharge and make a second test discharge, to avoid the possibility of the battery being put into service with any low cells in it caused by defective

Fig. 83. Wiring Diagram for Battery Test Discharge, Using Rheostat

assembly. The test is also made to determine its capacity. Capacity, however, does not necessarily indicate the completeness or incompleteness of the initial charge. The only sure indication is the maximum specific gravity reached in each cell. This test discharge should preferably be made at the normal discharge rate of the battery and may be carried out with the aid of a rheostat, as shown in Fig. 83, or, where one of this or similar type is not available, by constructing an emergency water rheostat, as shown in Fig. 84. The container should preferably be a wooden tub or an earthenware jar, as a metal container naturally would not be suitable, since the current could then follow a shorter path from the electrodes to the container instead of being compelled to pass through the solution between the electrodes. The

solution employed is weak electrolyte, while the electrodes may be either strips of metal or pieces of carbon. They should be mounted on a piece of board so that the distance between them may be adjusted, as the amount of current that flows will depend upon this distance. Separating them further will decrease the amount of current passing, while bringing them closer together will increase it, the rate of discharge being shown by the ammeter. In case the rate is too high at the maximum distance to which the electrodes can be separated, weaken the electrolyte solution of the rheostat by adding more water or, if necessary, make it plain water. If the rate of dis-

Fig. 84. Wiring Diagram for Battery Test Discharge, Using Water Rheostat

charge is insufficient even when the electrodes are brought close together, strengthen the electrolyte slightly. A convenient form for keeping the discharge record is shown by Fig. 85. Should a second test discharge be made, the capacity will be less than the first, but, after several discharges, the battery will not only recover but will exceed its first capacity.

Recharging. The battery should then be fully charged, and the specific gravity of the electrolyte adjusted to the proper point. On this occasion, all the precautions mentioned in connection with the initial charge and the polarity of the charging connections must be

observed. The battery should then be fully discharged. (Fig. 83 shows the method of connecting the battery to discharge through a rheostat, while the water resistance described is illustrated by Fig. 84.)

DATE Jan 14-1914 DISCHARGE No. 1

First discharge voltage reading to be taken for "Exide" cells at end of three and one-half (3½) hours; for "Hycap-Exide" cells at four and one-half (4½) hours; for "Thin-Exide" at five and one-half (5½) hours, and second reading twenty (20) minutes after first reading, third reading twenty (20) minutes after second reading. Final reading when several cells reach 1.7 volts, noting total elapsed time.

Additional readings may be recorded in blank columns, proper headings being filled in.

If this is final discharge before shipment, make a note to this effect in the space provided for remarks.

REMARKS:

Fig. 85. Specimen Battery Discharge Record
Courtesy of Electric Storage Battery Company, Philadelphia, Pennsylvania

If a suitable resistance is not at hand for this purpose, a water resistance may easily be made as follows:

Take a vessel of wood, or any other material except metal, and fill it almost full of a diluted solution of sulphuric acid and water. Connect the ammeter to one plate of metal and the battery to a second plate of metal, both of which should be suspended in the solution, care

being taken to prevent the current from passing from one plate to the other except through the solution. The remaining terminal of the battery and of the ammeter should be connected together. There is then a complete circuit through the improvised resistance, and the strength of the current may be varied by placing the plates nearer together or farther apart, or by adding acid to the solution, either of which operations will decrease the resistance. This should be adjusted until the ammeter shows that the battery is discharging through the resistance at its normal rate. After cleaning, the capacity of a battery may not be as great as it was previous to the operation until it has had several charges and discharges. While dismantled, the wood trays of the battery should be well rinsed with a strong solution of bicarbonate of soda and water in order to neutralize any acid on them. After that, they should be well rinsed with water and, when dry, painted with acid-resisting paint.

PUTTING BATTERY OUT OF COMMISSION

Methods of Storage. When a battery is not to be used for some time, it must be specially prepared before being stored. There are two general methods of preparing a battery for storage, one known as "wet storage" and the other as "dry storage", the method adopted depending upon the condition of the battery and the length of time it is to be out of commission. The wet-storage method is usually applied to any battery that is to be out of commission for less than a year, provided its condition is such that it will not soon require repairs necessitating dismantling it. The dry-storage method is used for any battery that is to be out of commission for more than a year, regardless of its condition, and it is also applied to any battery that will shortly require repairs necessitating its dismantling.

Wet Storage. Examine the condition of the plates and separators and also the amount of sediment in the bottom of the jars. If it is found that there is very little sediment and the plates and separators are in sufficiently good condition to give considerable additional service, the battery may be put into wet storage by giving it an equalizing charge and covering it to exclude dust. Replace evaporation periodically by adding distilled water to maintain the level of the electrolyte ½ inch above the top of the plates. At least once every four months, charge the battery at one-half the normal finishing

rate until all the cells have gassed continuously for at least three hours. Any cells not gassing should be examined and the trouble remedied.

Dry Storage. When the examination shows that the battery will soon require repairs that necessitate dismantling, it should be put into dry storage. Dismantle the battery in accordance with the instructions given in a preceding section under this head, first making the sketch of the layout and connections as there illustrated. If the positive plates show much wear, they should be scrapped; if not, remove any loose particles adhering to them by passing a smooth paddle over the surface but *do not wash the positive plates.* Charged negative plates will become hot in a short time when exposed to the air; they should be allowed to stand in the air until cooled.

Empty the electrolyte out of all the jars into a glazed earthenware jar or lead-lined tank and save it for giving the negative plates their final treatment before storage. Wash all the sediment out of the jars; wash the rubber separators carefully, dry them, and tie them in bundles. Place the positive groups in pairs, put them into jars, and store them away. Place the negative groups together in pairs, put into the remaining half of the jars, cover them with the electrolyte saved for the purpose, and allow them to stand in it for five hours at least. Then pour off the electrolyte, which may now be discarded, and store away the jars containing the negatives. If the negative plates showed any bulging of the active material, they should be subjected to the pressing treatment first, using boards and a vise as described in connection with dismantling the battery. The jars containing the positives, as well as those containing the negatives, should be well covered to exclude all dust.

Make a memorandum of the amount of material required to reassemble the battery and, when ordering this, provide for extra jars and covers, extra rubber separators, and an entire lot of wood separators, with a sufficient excess to take care of possible breakage in handling. Unless the old connectors were very carefully removed, order a new set. Include a supply of new electrolyte of 1.300 specific gravity to fill all the jars. It is always well to advise the customer when the battery is put in storage of the material that will be necessary to reassemble it and request that at least a month's notice be given in which to procure it. To reassemble the battery, proceed as in making a complete renewal of the elements.

MISCELLANEOUS OPERATIONS

Lead Burning. *Type of Outfit.* In the manufacture of storage batteries and in garages where a large number of batteries are maintained, a hydrogen-gas apparatus is employed for this purpose. For the electric-car owner or the garage doing a comparatively small amount of battery repair work, the Electric Storage Battery Company has placed an arc lead-burning outfit on the market. This is low in first cost and, with a little practice, good results can be obtained with it. As the battery itself supplies the power necessary, the only material required is the lead in the form of a flexible strip or heavy wire. The complete outfit is illustrated in Fig. 86. At one end is the clamp for making electrical connection, while at the other is a clamp of different form having an insulated handle and holding a quarter-inch carbon rod. The two are electrically connected by a flexible cable. This simple outfit can be employed in two ways, the second being preferable for the beginner, at least until a sufficient amount of skill has been acquired to use the arc without danger of melting the straps.

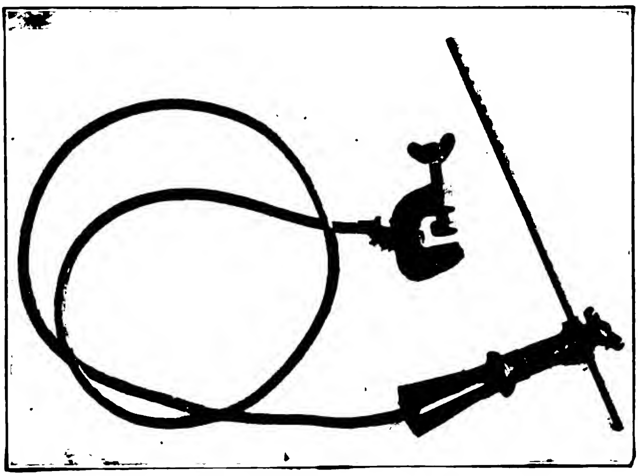

Fig. 86. Arc-Welding Outfit for Burning Connections

First Method of Burning. In the first method, a potential of from 28 to 30 volts (12 to 15 cells) is required. The clamp should, therefore, be fastened to the positive pole of the twelfth to the fifteenth cell away from the joint to be burned, counting toward the

negative terminal of the battery. The carbon then forms the negative terminal of the circuit. Otherwise particles of carbon will be carried into the joint, as the carbon rod quickly disintegrates when it forms the positive pole. The carbon should project 3 or 4 inches from the holder. The surfaces of the parts to be burned should be scraped clean and bright and small pieces of clean lead about $\frac{1}{4}$ to $\frac{1}{2}$ inch square provided for filling the joint. The carbon is then touched to the strap to be burned and immediately withdrawn, forming an electric arc which melts the lead very rapidly. By moving the carbon back and forth the arc is made to travel over the joint as desired, the small pieces of lead being dropped in to fill the gap as required. Owing to the high temperature generated, the work must be carried out very quickly, otherwise the whole strap is liable to melt and run.

As this method is difficult and requires practice to secure good results, the beginner should try his hand on some scrap pieces of lead before attempting to operate on a cell. Its advantages are that, when properly carried out, it takes but a short time to do the work, and the result is a neat and workmanlike joint. It is extremely hard on the eyes, however, and should never be attempted without wearing smoked or colored glasses, and even with this protection the eyes should be directed away from the work as much as possible.

Second Method of Burning. The second method, utilizing the hot point of the carbon rod instead of the arc, is recommended for general practice. Scrape the parts to be joined and connect the clamp between the third and fourth cells from the joint. With this method it is not necessary to determine the polarity of the carbon. The latter is simply touched to the joint and held there; on account of the heavy flow of current it rapidly becomes red- and then white-hot. By moving it around and always keeping it in contact with the metal, the joint can be puddled. To supply lead to fill the joint, an ordinary lead-burning strip can be used, simply introducing the end into the puddle of molten lead, touching the hot carbon. The carbon projecting out of the holder should be only an inch, or even less, in length. After the joint has been made, it can be smoothed off by running the carbon over it a second time.

Use of Forms to Cover Joint. In joining a strap which has been cut in the center, it is best to make a form around the strap by means of a piece of asbestos sheeting soaked in water and fastened around

the strap in the shape of a cup, which will prevent the lead from running down. It will be found that sheet asbestos paper is thick enough, but it should be fairly wet when applied. By this means a neat joint can be easily made. The asbestos will adhere very tightly to the metal, due to the heat, but can be removed by wetting it again. When burning a pillar post to a strap, a form may be made around the end of the strap in the same manner, though this is not necessary if reasonable care is used. Two or three pieces of $\frac{1}{16}$-inch

Fig. 87. Lead-Burning Outfit for Use with Illuminating Gas
Courtesy of Electric Storage Battery Company, Philadelphia, Pennsylvania

strap iron about one inch wide and some iron nuts about one inch square are also of service in making the joint, the strap iron to be used under the joints and the nuts at the side or ends to confine the molten lead. Clay can also be used in place of asbestos, wetting it to a stiff paste. As the holder is liable to become so hot from constant use as to damage the insulation, besides making it uncomfortable to hold, a pail of water should be handy and the carbon dipped into it from time to time. This will not affect its

operation in any way, as the carbon becomes hot again immediately the current passes through it.

Illuminating Gas Outfit. Heretofore it has not been possible to do good work in lead burning with illuminating gas, but a special type of burner has recently been perfected by the Electric Storage Battery Company which permits of the use of illuminating gas with satisfactory results. The outfit consists of a special burning tip and mixing valve. Sufficient $\frac{5}{16}$-inch rubber hose should be provided and the rubber should be wired firmly to the connections *A* and *B*, Fig. 87, as the air is used at a comparatively high pressure. A supply of compressed air is necessary, the proper pressure ranging from 5 to 10 pounds, depending upon the length of hose and the size of the parts to be burned. When air from a compressor used for pumping tires is utilized for this purpose, a suitable reducing valve must be introduced in the supply line. This outfit is designed for use with ordinary illuminating gas and cannot be employed with natural gas.

Connect the air hose to cock *A* and the gas hose to cock *B*. The leader hose, which should not be more than five or six feet long, is connected to the pipe *C* and to the burning tip *D*. When the air pressure at the source is properly adjusted, close the air cock *A* and turn the gas cock *B* on full. Light the gas at the tip and turn on the air. If the flame blows out, the air pressure is too high and should be reduced, preferably at the source. With the gas turned on full, the flame will have a ragged appearance and show a waist about $\frac{1}{2}$ inch from the end of the tip, the flame converging there and spreading out beyond. Such a flame is not for lead burning.

Slowly turn the gas off until the outer portion at the waist breaks and spreads with an inner tongue of flame issuing through the outer ring. The flame will now have a greenish color and is properly adjusted for burning. If the gas is turned off further or if too much air is turned on, the flame assumes a blue color gradually becoming invisible and is then deficient in heating power. When properly adjusted, the hottest part of the flame is just past the end of the inner point. Do not hold the flame too close to the work when burning, as its heating effect is greatly reduced and the flame is spread so as to make control difficult. The burning tip is provided with an outer sleeve and lock nut *E;* this sleeve is removable and can be taken off in case any of the holes in the tip become clogged. The position of

this sleeve is adjustable, the best position varying with the pressure of the flame, and it should be determined by experiment.

Hydrogen-Gas Outfit. Hydrogen gas gives a hotter flame and therefore permits of more rapid work, so that where burning is done on a large scale, it is still preferred. The essentials of such an outfit are: first, a hydrogen generator; second, a method of producing air pressure at approximately 2 pounds to the square inch; and third, the usual pipe and tips for burning. If hydrogen gas is purchased in a tank and compressed air is available, only the blow pipe, tips, and a reducing valve on the air line are necessary. This is an expensive method to purchase hydrogen, however, so that it is usually generated, and a water bottle is needed between the generator and the blow pipe to wash the gas and to prevent the flame from traveling back to the generator.

For this purpose hydrogen gas is generated by placing zinc in a sulphuric-acid solution. The generator usually employed for vehicle-battery burning requires 50 pounds of zinc, 2 gallons of sulphuric acid, and 9 gallons of water for a charge. Where no compressed-air supply is available, an air pump and an air tank for equalizing the pressure must be used. An outfit of this kind is shown in Fig. 88. In preparing the generator for use, connect up as shown in this cut, taking care that the hose from the generator is connected to the nipple of the water bottle *L*. Have the water bottle one-half to two-thirds full and immerse it in a pail of cold water up to its neck. Replace the water in the pail whenever it becomes warm. Have stop cock *N* closed. Put the required amount of zinc, which has been broken into pieces small enough to pass through the opening *C*, into lower reservoir. Put on cap *X* and screw down with clamp *D*, being sure that the rubber drainage stopper *H* is well secured in place. Pour the proper amount of water into reservoir *A* and then pour in the acid, taking care to avoid splashing. *Always pour the water in first.*

In running the hose from *K* to *N*, arrange it so that there will be no low points for the water of condensation to collect in; in other words, this hose should drain back at every point to the water bottle. If, however, water should collect in the hose to such an extent as to interfere with the flame and it cannot readily be drained off, kink the hose between *T* and *U* and detach it from *K*; close the stop cock at

W and pump until a strong pressure is obtained in the tank; then close the cock at *V*, opening those at *S* and *N* and, finally, quickly open *W*; the pressure in the air tank will then force the water out of the hose. The length of the hose from *T* to *U* should be such that the mixing cocks at *S* and *N* are always within easy reach of the man handling the flame.

In preparing the flame for burning, close the air cock at *S* and open *N* wide, hold a match to the gas until it lights, then add air and adjust the gas cock slowly, turning toward the closed position

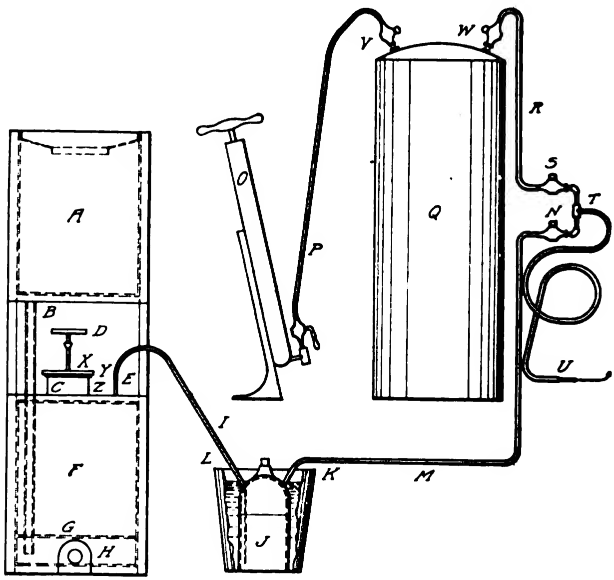

Fig. 88. Diagram of Lead-Burning Outfit, Using Hydrogen Gas

until the flame, when tried on a piece of lead, melts the metal and leaves a clean surface. The tip to be used depends on the work, but most vehicle-battery work is done with the medium tip. Replenish the zinc every few days, keeping it up to the required amount. When a charge is exhausted or the generator is to be laid up for the night, the old solution should be drawn off before making up a new charge and the generator thoroughly flushed out by running water through *A*. The new charge should not be put in until the generator is to be used again. To empty the generator, first pull off the hose at the nipple *K*, then at *E*, and finally the rubber plug at *H*. Take care not to

allow the solution to splash on anything and not to dump the generator where the contents will damage cement, asphalt, or wood walks.

Freezing. In addition to taking care that the temperature of the cells does not exceed 100° F. on charge, precautions are also necessary to prevent the temperature of the battery falling too low, as a drop in temperature causes a falling off in the efficiency. This is particularly true of the alkaline battery, the output curve of which drops off rapidly below 60° F., so that this type of battery is usually installed in a manner which keeps it at an even temperature, making it possible to operate it successfully in zero weather. Furthermore, in the case of the lead cell, freezing must be guarded against. To avoid this, the battery should always be kept fully charged in cold weather, as a charged cell will not freeze in the temperatures ordinarily experienced. Electrolyte will freeze at various temperatures, according to the state of charge as follows:

Sp. Gr. 1.120 battery fully discharged	20° F. above zero
Sp. Gr. 1.160 battery three-quarters discharged	Zero F.
Sp. Gr. 1.210 battery half-discharged	20° F. below zero
Sp. Gr. 1.260 battery one-quarter discharged	60° F. below zero

When a battery is stored away for the winter, care should be taken not to let the temperature of the place in which it is kept fall below 20° F., or else the battery should be kept fully charged.

Putting New Battery in Commission. One of the things that the garage man caring for electric vehicles will be called upon to do at intervals will be the ordering and installation of a new battery in a car. As received from the manufacturer, the battery is in a charged condition, that is, it was fully charged just previous to being shipped, but it must be inspected and tested before being placed in the car.

Inspection of Battery. To avoid spilling the electrolyte from the cells, care must be taken in unpacking the trays. After cleaning off the excelsior and other packing from the tops of the cells, the soft rubber plugs should be removed from all the latter to note if they all contain the proper amount of electrolyte. This should be ½ inch over the tops of the plates. If the electrolyte is uniformly below the proper level in all the cells, this is evidently due to evaporation; add enough distilled or rain water to bring the level to the proper height. But if the level of the electrolyte is found to be low in some cells only, this is due to loss of electrolyte. If this has resulted from the tray

having been turned over in shipment, the excelsior around the top of the tray will be wet (the acid does not evaporate), and some acid would be spilled from *all* the cells in that tray. In this case, replace the amount lost by filling the low cells to the proper height with chemically pure electrolyte of 1.250 specific gravity (seven parts of water to two pure sulphuric acid, by volume).

Replacements. If the electrolyte in a cell is low, due to a broken jar, the bottom of the tray will be wet, though the excelsior around the the top may be dry. Replace the broken jar as detailed in the instructions given under that heading and add sufficient electrolyte of 1.250 specific gravity to make up for that lost. Should it be found, after replacing the broken jar and giving the battery an equalizing charge, that the gravity does not reach approximately 1.275, it is due to not having replaced the same amount of acid as was spilled. To adjust this, draw off with a syringe some of the electrolyte from the top of the cell and add water or 1.300 acid to bring the specific gravity to between 1.270 and 1.280.

Charging. Put the battery on charge at the low rate given on the name plate on each tray. Charge at about this rate until all the cells gas uniformly. Reduce the current to one-half that rate and continue the charge for three hours longer, when the battery will be ready to put into service. It is advisable, however, before putting the battery into service, to take and record the specific gravity of the electrolyte of each cell and the temperature of one or more of the cells.

Packing a Battery. It is sometimes necessary to ship a battery back to the manufacturer for repairs, and the amount of damage occasioned in transit by improper packing has led the makers to issue special instructions for doing this. A box at least 2 inches larger in each direction than the overall size of the battery tray should be made of strong 1-inch or $1\frac{1}{4}$-inch planks. It should be made with an A-shaped top to prevent placing it any other way than upright. Where more than one tray is shipped in a box, 2 inches must be allowed between the trays. The maximum permissible weight, however, is 200 pounds. Cover the bottom of the box with a layer of sawdust, excelsior, or coarse shavings to a depth of 2 inches, and on this place the tray of cells. Over the top of the cells place paraffined paper and then cover the whole tray with stout wrapping paper, folding it down over the sides of the tray to keep packing material and dust out of

the cells. Fill the space around the sides with sawdust or excelsior, or even with waste paper twisted into balls and wads, ramming the whole down tightly so that the tray cannot move. Nail slats on the box for a cover (never make a solid cover), and nail a stout strip on each side extending beyond the ends, for handles. The slatted cover enables the freight handlers to see the contents and makes for more careful handling. Label the box "handle with care" and "do not drop". Put your own name and address on the package as well as that of the battery manufacturer, and notify the latter of the shipment. Complete batteries should be shipped as "electric storage batteries assembled". No railroad caution labels are required as the electrolyte in the cells is so dilute that acid in this form is exempted from the rules applying to its shipment in other forms. Boxes of good elements, or plates, should be shipped as "Lead Battery Plates", while worn-out plates may be shipped as "Scrap Lead", boxes of jars as "Rubber Battery Jars", covers and separators as "Rubber Goods", and empty trays as "Empty Wood Crates". By properly designating the material as above in the bill of lading, the most favorable freight rate may be obtained.

Causes of Low Battery Power. A decrease in the speed or mileage of a car does not necessarily mean a lack of capacity in the battery. If the current consumption is greater than normal, it may be due to trouble with the transmission, motor, or running gear—the car "runs hard"—or it may be due to poor connections. When other causes fail, then it is probably the battery, and its lack of capacity may always be traced to some definite cause. There may be a dry cell, due to a leaky jar; some or all of the cells may be in a state of incomplete charge, due to the battery having been run too low and not sufficiently charged. The plates may be short-circuited by excessive deposit of sediment, or by something falling into the jar.

If the trouble cannot be located upon examination, connect the battery in series and discharge it at the normal rate through a suitable resistance, as already explained. As the discharge progresses the voltage will gradually decrease, and it should be frequently read at the battery terminals. As soon as it shows a sudden drop, the voltage of each cell should be taken with a low-reading voltmeter. While the readings are being taken, the discharge rate should be maintained constant, and the discharge continued until the majority of the cells

read 1.70 volts. Those reading less than this should be noted. The discharge should then be followed by a charge until the cells which show 1.70 volts are up. Then the low cells should be cut out and examined and the trouble remedied. Assuming that there are no short-circuits, low specific gravity of the electrolyte in such a cell will indicate sloppage or a leak, the loss from which has been replenished with water alone. Or it will be a sign of insufficient charge, over-discharge, standing in a discharged condition, or a combination of these abuses. Any one of these indicates that there is acid in combination with the active material of the plates, and it should be brought out by a long charge at one-quarter the normal discharge rate. Continue charging until the specific gravity of the electrolyte stops rising; then adjust to normal (1.270 to 1.280) by drawing off some of the electrolyte and adding water if it be above normal, and by adding acid if it be below normal. The low cells should be grouped by themselves and charged as a separate battery.

STANDARD INSTRUCTIONS FOR STORAGE BATTERIES

As Issued by the Society of Automobile Engineers

1. Batteries must be properly installed.

Keep battery securely fastened in place.

Battery must be accessible to facilitate regular adding of water to, and occasional testing of, solution. Battery compartment must be ventilated and drained, must keep out water, oil, and dirt and must not afford opportunity for anything to be laid on top of battery. Battery should have free air space on all sides, should rest on cleats rather than on a solid bottom and holding devices should grip case or case handles. A cover, cleat, or bar pressing down on the cells or terminals must not be used.

2. Keep battery and interior of battery compartment wiped clean and dry.

Do not permit an open flame near the battery.

Keep all small articles, especially of metal, out of, and away from, the battery. Keep terminals and connections coated with vaseline or grease. If solution has slopped or spilled, wipe off with waste wet with ammonia water.

3. Pure water must be added to all cells regularly and at sufficiently frequent intervals to keep the solution at the proper height.

The proper height for the solution is usually given on the instruction- or name-plate on the battery. In all cases the solution must cover the battery plates.

The frequency with which water must be added depends largely upon the battery, the system with which it is used, and the condition of operation. Once every two weeks is recommended as good practice in cool weather; once every week in hot weather.

Plugs must be removed to add water; then replaced and screwed home after filling.

Do not use acid or electrolyte, only pure water.

Do not use any water known to contain even small quantities of salts of any kind. Distilled water, melted artificial ice, or fresh rain water are recommended.

Use only a clean non-metallic vessel.

Add water regularly, although the battery may seem to work all right without it.

4. The best way to ascertain the condition of the battery is to test the specific gravity (density) of the solution in each cell with a hydrometer.

This should be done regularly.

A convenient time is when adding water, but the reading should be taken before, rather than after, adding the water.

A reliable specific gravity test cannot be made after adding water and before it has been mixed by charging the battery or by running the car.

To take a reading, insert the end of the rubber tube in the cell. Squeeze and then slowly release the rubber bulb, drawing up electrolyte from the cell until the hydrometer floats. The reading on the graduated stem of the hydrometer at the point where it emerges from the solution is the specific gravity of the electrolyte. After testing, *the electrolyte must always be returned to the cell from which it was drawn.*

The gravity reading is expressed in "points", thus the difference between 1250 and 1275 is 25 points.

5. When all cells are in good order the gravity will test about the same (within 25 points) in all.

Gravity above 1200 indicates battery more than half charged.

Gravity below 1200 but above 1150 indicates battery less than half charged.

When battery is found to be half discharged, use lamps sparingly until, by charging the battery, the gravity is restored to at least 1200. See Section 8.

Gravity below 1150 indicates battery completely discharged or "run down".

A run-down battery should be given a full charge at once. See Sections 7 and 8.

A run-down battery is always the result of lack of charge or waste of current. If, after having been fully charged, the battery soon runs down again, there is trouble somewhere else in the system, which should be located and corrected.

Putting acid or electrolyte into the cells to bring up specific gravity can do no good and may do great harm. Acid or electrolyte should never be put into the battery except by an experienced battery man.

6. Gravity in one cell markedly lower than in the others, especially if successive readings show the difference to be increasing, indicates that the cell is not in good order.

If the cell also regularly requires more water than the others, a leaky jar is indicated.

Even a slow leak will rob a cell of all its electrolyte in time, and a leaky jar should be immediately replaced with a good one.

If there is no leak and if the gravity is, or becomes, 50 to 75 points below that in the other cells, a partial short-circuit or other trouble within the cell is indicated.

A partial short-circuit may, if neglected, seriously injure the battery and should receive the prompt attention of a good battery repair man.

7. **A battery charge is complete when, with charging current flowing at the rate given on the instruction-plate on the battery, all cells are gassing (bubbling) freely and evenly and the gravity of all cells has shown no further rise during one hour.**

The gravity of the solution in cells fully charged as above is 1,275 to 1,300.

8. **The best results in both starting and in lighting service will be obtained when the system is so designed and adjusted that the battery is normally kept well charged, but without excessive overcharging.**

If, for any reason, an extra charge to maximum specific gravity is needed, it may be accomplished by running the engine idle, or by using direct current from an outside source.

In charging from an outside source use *direct* current only. Limit the current to the proper rate in amperes by connecting a suitable resistance in series with the battery. Incandescent lamps are convenient for this purpose.

Connect the positive battery terminal (painted red, or marked POS or P or +) to the positive charging wire and negative to negative. If reversed, serious injury may result. Test charging wires for positive and negative with a voltmeter or by dipping the ends in a glass of water containing a few drops of electrolyte, when bubbles will form on the negative wire.

9. **A battery which is to stand idle should first be fully charged. See Sections 7 and 8.**

A battery not in active service may be kept in condition for use by giving it a freshening charge at least once every two months, but should preferably also be given a thorough charge, after an idle period, before it is replaced in service.

A battery which has stood idle for more than two months should be charged at one-half normal rate to maximum gravity before being replaced in service.

It is not wise to permit a battery to stand for more than six months without charging.

Disconnect the leads from a battery that is not in service so that it may not lose through any slight leak in car wiring.

SOME SOURCES OF POWER LOSS

As the power of the electric vehicle is closely limited by the capacity of the battery it carries, it is absolutely essential that every part of the mechanism be kept in good running order so that none of the power may be wasted. Whether the machine is considered as a whole, or each component is treated separately, the electric vehicle is about as simple as it possibly could be. But the number of places at which power losses may occur will greatly surprise the uninitiated owner when he comes to look into the subject. It is nothing unusual for the purchaser of an electric vehicle to write the maker a year or so after he has bought it that while the car ran perfectly satisfactorily at first, its mileage has now been very much reduced. He has followed instructions implicitly, the battery has been well looked after, and, according to all indications, it is in as good

condition as ever it was, but it is impossible to obtain anything like the rated mileage from a full charge of the battery. A little investigation will show that, in the majority of cases, the owner, who has not had the advantage of a mechanical training, has become so impressed with the great importance of properly maintaining the electrical end of the car that he has disregarded its mechanical efficiency entirely.

Non-Alignment of Steering Wheels. One of the most prolific sources of power losses, and one of the last to be suspected, is non-alignment of the wheels. A chance blow in drawing up alongside a curb is sometimes sufficient to make one of the front wheels "toe in" slightly. The fault is not noticed and may be aggravated by subsequent blows at the same spot, or on the other wheel. This may cause the bearings to bind to a certain degree and also to impose a heavy load on the motor by the new angle which the tires make with the road surface. It is difficult for the average layman to appreciate how great an increase in the load such a seemingly trivial fault as this may create, and it can only be realized to a certainty by keeping a record of the ammeter readings at all of the speeds under normal conditions. Just how much current is required to start and to mount various grades should be noted. As the service of an electric vehicle is chiefly confined to urban travel and covers practically the same routes day after day, it is possible to keep a close check on current consumption by noting how far the ammeter needle travels over the dial in running on the level and in mounting grades that have to be climbed frequently. Small increases in the current required to do the same work at different times would then be readily apparent, and as the malady is imposing an extra drain on the battery, which is simply a waste of energy, its cause should be looked for and remedied.

The electric vehicle is a power-measuring machine without an equal, and the driver who has familiarized himself with the performance of his car under favorable conditions should be able readily to detect the presence of trouble by the increased current consumption and the correspondingly decreased mileage per charge. The causes may be electrical as well as mechanical, and where a car has not been properly looked after, it is more than likely that the falling off in the available radius on a single charge will be traceable to an

accumulation of causes small in themselves, but of considerable importance in the aggregate. Disalignment of the front wheels may sometimes be due to the steering gear—that is, the connecting rod which serves to keep these wheels parallel—working out of adjustment. Unless they are perfectly aligned, they not only make more current necessary to propel the vehicle, but they also serve to wear out the front tires more rapidly than would otherwise be the case. Sagging of the rear axle, which was not an uncommon fault in earlier years, but which is now rare, will produce similar conditions at the rear wheels and, as the entire power of the car is utilized at this point, the result is just that much worse.

Worn Chains and Sprockets. Next in the order of importance to badly aligned driving or steering wheels from a mechanical point of view, comes a worn driving chain. This naturally applies to the chains employed for either of the reductions in motor speed. It is likewise equally true of the sprockets, but a worn sprocket is practically always the result of the continued use of an old chain. The latter is allowed to wear to a point where its pitch is greater than that of the teeth of the sprocket, and, in consequence, the chain shows a constant tendency to ride the teeth of the sprocket instead of fitting snugly between them, as should be the case. This tightens the chain and imposes a greatly added load upon it and the sprocket, with the result that the teeth of the latter are also soon worn out of pitch. When this occurs, the only remedy lies in the replacement of both chains and sprockets, as the fitting of a new chain on a worn sprocket aggravates the evil and causes the new chain to wear to a point of uselessness in a very short time. The best preventive is to watch the driving chains for such conditions and to replace a chain as soon as it gives any indication of mounting the teeth instead of running smoothly.

These instructions apply only to pleasure models antedating 1913-14, as practically all models are now made with the shaft drive using a bevel gear or worm; but there are thousands of the older chain-driven cars in service, the electric having a much longer effective life than the gasoline car.

Non-Alignment of Axles. On all electric cars, whether chain- or shaft-driven—the former being greatly in the majority, of course—means are provided for aligning the rear axle. These take the form

of *distance* or *radius rods*, attached through the medium of a hinge joint to the axle and some form of pivot joint at the countershaft, this construction having been referred to in connection with the description of the transmission of a double chain-driven car. Although effective means of locking these rods are provided, they are subjected to constant vibration and jolting and sooner or later will require attention. It will be apparent that if one is adjusted so as to be somewhat shorter than the other, an excessive fraction of the load will be imposed on the driving chain on the short side. This will also place a very heavy strain on the differential or balance gear, and a greatly added amount of power will be required to drive the car. The importance of accurately adjusting the distance rods so that the rear axle will be at right angles with the frame and of maintaining it in that condition may accordingly be appreciated.

Dry Bearings. It would appear almost superfluous to mention lack of oil as a mechanical source of power loss, but many electric vehicle owners seldom attach sufficient importance to the necessity for oiling the moving parts. It is a popular fallacy, quite generally indulged in, that the anti-friction bearing is a mechanical device that requires no lubrication. Ball bearings do call for less attention in this direction than any other. They need very little oil, and at much longer intervals than a plain bearing, but they cannot render efficient service without some lubricant. In fact, it is this very ability to stand an uncommon amount of abuse that seems to have earned for the ball bearing its popular reputation for ability to run quite as well whether it is dry or oiled. The lubricant not only serves the same end that it does in any bearing—that of reducing friction, but it also acts as a preventive of rust—the greatest enemy of the ball bearing; and as these bearings are very expensive replacements, it pays to avoid this by regular oiling at least once a month. Only the best grade of light machine oil should be employed, or a thin-bodied and highly-refined vaseline with which the bearing may be packed. It is quite essential that the lubricant should be entirely free from acid, which would attack the highly polished surfaces of the balls and races and destroy the efficiency of the bearing. The electric-vehicle user's chief safeguard against this is to confine his purchases to brands recommended by the manufacturer of the car. Where the presence of acid is suspected, a simple test may be made by

dipping a small piece of cotton waste in the lubricant and then wrapping it around a piece of polished steel. This should be placed in the sun and examined at the end of a week or more. If the lubricant contains acid, there will be traces of its etching effect on the polished surfaces and it is useless. Oil that is entirely free from acid will not affect the most highly polished surface.

Wheels and axles out of alignment, worn chains and sprockets, improperly adjusted brakes, which may be dragging, and neglected bearings sum up the chief mechanical sources of power loss.

It is quite as important, however, that losses of electric power be guarded against, as they interfere with the efficient utilization of the energy stored in the batteries and decrease the available mileage on a charge, regardless of the condition of the mechanism. Vibration will prove the undoing of almost anything in the course of time, and, while every precaution is taken by the manufacturer to provide durable and permanent connections, it seems practically impossible to provide a form of terminal that will be absolutely proof against this influence and still permit of being disconnected conveniently when required. Air interposes a very high resistance in a circuit, and but a slight amount of looseness in a connection creates an air gap that must be bridged by the current in order to complete the circuit. This causes *arcing*, or a flashing of the current across the gap, which is destructive of the terminals and is not infrequently responsible for the ignition of adjacent material. As will be apparent from the wiring diagram given, there are quite a number of such connections, and going over them systematically at regular intervals is the only way to guard against current losses from this source.

Brushes and Commutator. The brushes and commutator are the only parts of the electric motor that are subject to wear, and the life of the commutator is naturally equivalent to that of several sets of brushes, so that the latter constitute practically the sole item to be looked after in connection with the motor. They are either plain blocks of carbon, or carbon with fine copper wire embedded in it, and are held against the commutator by springs. To examine their condition closely, the housing should be removed, the rear axle jacked up, and the motor run on the first speed. No attempt should be made to run it on any of the other speeds when in this condition, nor should it be run any longer than necessary. This does not

exactly simulate actual driving conditions as, with the wheels off the ground, practically no load is imposed on the motor and, while the latter may spark badly under load, it will frequently give little indication of this form of trouble when running light.

If the brushes have been sparking badly in actual service there will be certain signs of this in the shape of the blackened commutator bars. They should be wiped clean and, if any oil has leaked on to them from the bearing, all traces of it should be removed. If this does not suffice to remove the blackened appearance, the sparking has been such as to burn the copper, and this blackened surface should be removed with the aid of a piece of very fine sandpaper held against the commutator while it is turning slowly. Never use emery cloth for this purpose, as the abrasive material employed in its manufacture is of a metallic nature, and not only tends to embed itself in the insulation between the bars, but, once there, serves as a conductor and may short-circuit some of the armature coils, resulting in serious damage to the motor. If the brushes merely appear to be glazed but still make good contact all over the bearing surface, the latter may be rubbed with the sandpaper as well. If they have worn to a point where the contact is not good, new brushes should be substituted, and it would be well for the owner of the electric vehicle who is not familiar with the motor, to have an experienced person put them in for him the first time—every time, in fact, unless he is perfectly sure of his own ability in this line. A set of brushes will seldom, if ever, need replacement more than once during an entire season.

For instructions covering seating of brushes, testing springs, and the like, refer to sections on these faults in the article on Starting Motors and Lighting Generators.

Armature Troubles. When the housing is off, the brush connections and other motor connections should be inspected for looseness or other faults. Instructions for locating grounds, short-circuits, or open circuits in the armature and field windings are given in connection with the articles on Starting and Lighting Systems.

The armature is supported on annular ball bearings in the majority of cases, and while these bearings require periodical oiling as much as the remaining ones of their kind on the car, pains must be taken

to use the oil sparingly in order to prevent it reaching the commutator at one end or the armature windings at the other.

Miscellaneous. In speaking of connections, those at the battery are included and they should be inspected as well. The connections between the different cells are usually made by burning the lead-strap terminals together, though some have bolted connections, and these may jar loose; but the various groups are connected to one another and to the remaining apparatus, and these terminals are probably more apt to give trouble than some of the others, as it is nothing unusual to remove the battery at times and sufficient care is not always exercised to have the connections solidly fast.

The loss of electrical energy, due to undercharged and short-circuited cells in the battery, has been treated in detail in connection with the care of the battery.

Tires are, without doubt, one of the greatest sources of power loss on the electric vehicle, and it is one that mystifies the uninitiated exceedingly. This matter is gone into at length in connection with tire equipment.

TIRES AND MILEAGE

Relation of Tires to Mileage. It will appear odd and somewhat inexplicable at first sight that these two headings should be included in the same chapter, for the average man thinks that the only thing which has any direct influence on the mileage of the car is the amount of energy the battery is capable of giving forth. As is pointed out under "Sources of Power Loss", there are many other factors that affect the available radius of the car more or less indirectly. Tires are not included among these indirect sources, as the tire equipment has a *most direct* and, therefore, a most important bearing on the distance the electric car is capable of traveling on a single charge of the battery. The gasoline machine is endowed with such a liberal surplus of driving power that the loss occasioned by tires represents but an insignificant fraction of the whole; in other words, is a totally negligible factor. Had it not been for extensive experiments carried out in connection with the electric automobile, the importance of these losses would not have been definitely known.

When all the points which contribute to both the electrical and mechanical efficiency of the car have been carefully maintained in

proper working order, and still both the speed and total capacity of the battery fail to respond, the cause of the trouble may be summed up in a single word—"tires". For tires constitute the most important element in the determination of mileage and, though that fact is seldom, if ever, mentioned in connection with accounts of phenomenal mileages made on a single charge, they are the chief controlling factor. The tires usually employed for such "stunts" are specially made for the purpose and are not adapted to ordinary service. They have extremely thin walls, with the thread of the fabric reinforcement running continuously round the tread of the tire in the same direction, and are not only very likely to puncture on slight provocation, but are far from durable. The expense of employing such tires regularly would be prohibitive, particularly as they are very difficult to repair when punctured.

Kinds of Tires. *Pneumatic.* For the usual pleasure-car service, electric-vehicle manufacturers fit tires that experience has shown not alone to be best adapted to the peculiar needs of this type of automobile, but likewise sufficiently durable for the purpose. Pneumatic tires are a luxury and will always be a source of considerable expense, so that tire life is a factor to be taken quite as much into consideration as battery mileage. On the gasoline car, in view of the great weights and high speeds, it is solely a question of being able to make the pneumatic tire sufficiently strong to stand the unusually severe stresses to which it is subjected. To accomplish this end, the fabric structure forming the foundation of the shoe, or outer envelope of the tire, is made of various layers of heavy canvas placed at angles to one another and solidly vulcanized together. This construction makes an extremely stiff wall, as is evidenced by the difficulty in forcing a clincher type of tire on to the rim. Such a tire will yield to the minimum degree under the weight of the car or road obstacles when inflated to the proper pressure. In consequence, it absorbs an enormous amount of power. This loss is still further increased by the use of chains, studs, or similar anti-skid devices. Tests made on the recording dynamometer of the Automobile Club of America in New York City have shown that some forms of non-skid treads, particularly those employing heavy steel studs embedded in thick leather, absorbed as much as 5 horsepower per wheel to drive them. Tests showing 2 to 2½ horsepower per wheel were not

uncommon, and in but few instances did the loss drop below 1 horsepower per driving wheel, regardless of the type of tire employed.

It would be manifestly out of the question to expect much in the way of mileage from an electric vehicle if handicapped in this manner. Non-skid devices of any kind are rarely seen on electric automobiles for this reason, about the only occasion when they are in evidence being in winter, when they are actually required on ice or slushy pavements to afford sufficient traction. For electric service a structure is required in which the fabric foundation is so constituted as to be able to adapt itself most readily to the distortion caused by being pressed out flat on its contact area with the road. A tire constructed wholly of rubber, such as an inner tube, would be ideal, but wholly impracticable. The conditions to be met represent but another instance of the conflicting requirements found on every hand in automobile design. In other words, it is axiomatic that the ease with which a tire punctures is in direct proportion to the ease with which it runs.

Next to a pure rubber tire comes one in which threads or cords are individually embedded in the rubber. It will be apparent that such a tire is far more frail than those in which stiff canvas is employed as a foundation, and that the individual threads do not present any effective resistance to puncture. To be efficient from the point of service, it has been found essential to make a tire in two parts, i. e., a tube of pure rubber as an air container, and a shoe or outer protective cover to take the strain. Experiments with the single-tube tire or "hose-pipe" type,—that is, one in which the air container and the shoe are one—demonstrated that it was utterly unfitted for gasoline-car work. But the addition of the tube is another item that serves to cut down the power of an electric car.

Solid. Viewed from one aspect, the electric has an advantage over the gasoline car. Owing to its greatly reduced speed, the owner of an electric finds the solid-rubber tire a practical option. Naturally, there can be no comparison between the riding qualities of a solid and a pneumatic tire, b t as most electric-vehicle work is over smoothly paved streets, and the reasonable driver should never take obstructions except at a greatly reduced speed, the solid tire provides an amount of comfort out of proportion to its greatly reduced cost as compared with the pneumatic. The mileage radius

possible with a good solid tire is about the same as that possible with the standard fabric type of pneumatic usually referred to by the electric-vehicle manufacturer as a "gasoline" type of tire, with the advantage in favor of the former in that it is free from puncture.

Test Curves. An extensive investigation has been made of the subject of tires in the past few years and considerable data compiled. Herewith is given a series of curves prepared by the builders of the Rauch and Lang electrics which will suffice to reveal the great differences in tires where the question of mileage is concerned, Fig. 89. The curves show that of the solid types experimented with the

Fig. 89. Curves Showing Tests of Various Tires Made by Rauch and Lang Carriage Company

Motz tire rendered the best performance. On referring to the chart, it will be apparent that the showing of the tire in question is somewhat more uniform than the Diamond pneumatic type. At the high limit of the range is to be found the Palmer cord tire, which is a single-tube type of pneumatic with thread fabric. Bearing in mind the fact that increasing speed means a corresponding reduction in the mileage, the application of the chart is simple. Taking the Palmer tire just referred to as an example, select in the vertical column at the left marked "miles per hour", the rate at which the car is to travel. Trace this along the horizontal line representing the speed, to the right, until it intersects the characteristic curve of the tire in question. At that point, rise perpendicularly to the point

where the vertical line meets the top of the chart, which is divided into sections giving total mileage, by increments of 10 miles. For instance, suppose it be desired to run a car at 15 miles an hour on Palmer cord tires. Tracing the 15-mile line to the right, it will be found to intersect the Palmer-tire curve at the vertical line corresponding to 100 miles. A striking example of the manner in which mileage increases with reduced speed may be seen by tracing the 12½-mile line to the right until it intersects the Palmer curve. It gives a total mileage of 123, or an increase of 23 per cent in the distance covered for a decrease of but 2½ miles per hour in the speed. By making a further reduction to 10 miles an hour, 130 miles could be covered on a charge. This, of course, is not due to any characteristic of the tire, but to the fact that the lower the discharge rate the greater the capacity of the battery, the phenomenal mileages given being the result of employing a tire that presents the minimum of resistance to bending.

Such a tire, however, is not only high as to initial cost but it is also most susceptible to puncture and difficult of repair, and for these reasons is not available for the average user of an electric. The expense would be practically prohibitive. The chart shows the Morgan and Wright thread-fabric Dunlop to be capable of a very excellent speed and mileage performance, and for those who are desirous of combining these qualities in an electric, even at an increased cost for tire equipment, the vehicle makers recommend it. Its liability to puncture is less, and it will give reasonably good service, commensurate, of course, with the care given it. The solid tire at a 10-mile-an-hour speed is seen to be superior to the gasoline type of pneumatic, the latter falling below it in point of total distance by fully 12 miles.

New Tire Equipment. A little study of the foregoing will serve to reveal one of the most prolific causes of complaint on the part of uninitiated owners of electric vehicles. After wearing out one or two tires in service, they instruct the garagemen to put "new ones" in their place, or they renew the old ones by purchasing in the open market themselves. Unless informed as to the purpose for which the tires are needed, both the garagemen and the tire salesman are more than apt to supply a gasoline type of tire. A distinct falling off in the mileage radius of the car is at once noticeable, particularly

if the owner has been in the habit of making use of the higher speeds. The cause is apparently inexplicable, and the result is a complaint to the manufacturer that something has gone wrong or that the car is not fulfilling the promises made for it, when, as a matter of fact, greater care should have been taken to maintain the tire equipment the same throughout. "A chain is as strong as its weakest link," and an electric is only as fast as its slowest tire. Every electric driver should learn the name of the tire which the manufacturer has tested out and proved to give satisfaction and stick to this make. Something "just as good" will not do.

Improper Inflation. Tires have been previously mentioned as one of the sources of power loss, and the foregoing serves to explain to a great degree why this is so. An item of considerable importance in the treatment of tires, which has not been referred to, is improper inflation. A soft tire naturally consumes more power to drive it because of the increased friction due to the greater area of the tire in contact with the ground. Such a condition is detrimental to the tire itself as it increases the amount of wear and the danger of rim cuts. As a means of guarding against this, air-pressure gages are most frequently recommended, but their use merely affords an arbitrary standard of pressure that it is not always adaptable to the conditions. As an ideal condition, a tire should only be pumped sufficiently hard to properly carry the load imposed upon it, and with a little practice one can readily determine by the eye whether this point has been reached.

If the tire be too soft, the weight of the car will cause it to spread unduly at the point of contact with the road and this condition will be immediately noticeable. On the other hand, when the tire is pumped up too hard, the tire will stand just as if it were bearing no load. Such a condition obviously places too great a strain on both the fabric and the rubber, and is frequently the cause of tire failures that are usually assigned to a totally different reason. With its ordinary load of passengers, the electric should only cause a slight flattening of the tires at the tread, experiment showing that the best results are obtained when the increase in the width of the tire is about 20 to 25 per cent, that is, a 3-inch tire when properly inflated should measure approximately $3\frac{5}{8}$ inches across its horizontal diameter at the part in contact with the road.

Fig. 90. General Electric Volt-Ammeter

Fig. 91. Volt-Ammeter with Cushion Base

ELECTRIC INDICATING INSTRUMENTS AND THEIR USES

Volt-Ammeter. With an electric, it is important to watch the volt-ammeter. An example of this type of combined instrument is shown by the accompanying illustration, Fig. 90. It will be noted that the indicating needle of the ammeter does not go to the end of its scale, but reads both ways, the scale to the left hand being for the charging current, and that to the right for the discharging current. These instruments are manufactured in various forms, one type very much in use having the voltmeter and ammeter scales parallel in a vertical plane. Some also have the voltmeter scale so divided that the reading of the individual cells may be taken. To be accurate, the armature of such instruments must be very carefully adjusted on jeweled bearings almost as delicate as those of a watch, and as the vibration and jolting of the vehicle are naturally detrimental to the maintenance of its accuracy, volt-ammeters are now being built with a cushion base, as shown in Fig. 91.

By becoming familiar with the readings of the instrument and by realizing their significance, the driver of an electric automobile is in a position not only to judge whether the battery is giving the proper service, but he also has an accurate gage on the condition of the running gear and transmission of the vehicle itself. The instrument is capable, therefore, of giving ample warning by its deflections of any weakness, whether electrical or mechanical.

Ampere-Hour Meter. While the volt-ammeter affords a constant indication of the working of the battery, as well as the efficiency of the transmission, and is accordingly indispensable, it does not permit of the direct reading of the state of charge nor indicate offhand how much of the energy has been utilized and how much remains available at any given time. For this purpose the Sangamo ampere-hour meter has been developed and generally adopted by the builders of both pleasure and commercial electric cars. Faraday's law shows a definite relation between the mass of material transferred from the plates to the electrolyte of a storage cell and the ampere hours. That is, if the number of ampere hours absorbed by the battery is known, there is a direct measure of its state of charge, and consequently an ampere-hour meter may be used as a charge indicator.

Method of Use. To keep the battery plates in good working condition, it is necessary to give the battery a certain amount of charge, so that under normal conditions more ampere hours must be put into the battery than can be taken out of it. (See Fig. 11, Part 1, page 27.) This difference is the overcharge, and it must be taken into account in figuring the number of ampere hours in a battery available for useful work. Since the only information desired by the driver is how much energy can be taken from the battery, the Sangamo ampere-hour meter is designed to compensate for the overcharge, and indicates at all times the current available without the necessity of resetting the pointer every time the battery is charged. This is accomplished by means of a differential shunt, as shown by the diagram, Fig. 92. Two shunts are employed, and the relative value of their resistance is adjustable by means of the sliding connection *G*, so that the meter can be made to run slow on charge or fast on discharge, as desired. The usual method is to allow the meter to register less than the true amount on charge and the exact amount on discharge, the difference representing the loss in the battery, or overcharge. Thus the battery and the meter will keep in step for considerable periods without readjustment.

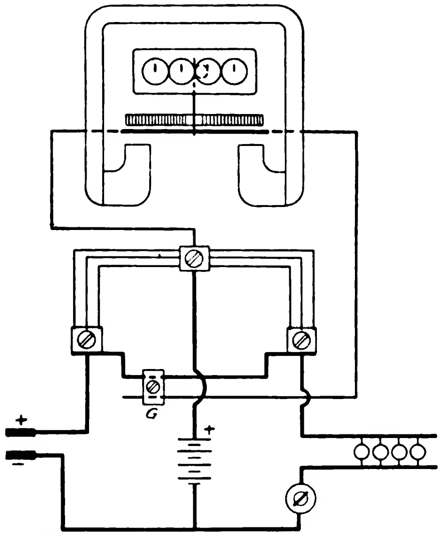

Fig. 92. Circuit Diagram of Differential Shunt Type Sangamo Ampere-Hour Meter

Readjusting the Meter. However, over long periods of use under varying conditions, the battery losses will vary and in time the meter and battery will get out of step. Therefore, it is good practice to give the battery an extra overcharge at stated intervals and reset the meter, a simple device being provided for this purpose. Moreover, in vehicle work the batteries are frequently subjected to excessively high discharge rates and, under such conditions, the

battery suffers an actual loss of capacity, which requires further compensation, as otherwise the meter will give a false indication of

Fig. 93. Variation of Useful Ampere-Hour Capacity of Lead Battery with Discharge Rate

the number of ampere hours available. The variation in the capacity of the battery with its discharge rate is shown by the curves, Fig. 99. To make clear the method of compensating for this loss, a brief description of the meter itself is given.

Description of Construction Features. This meter is known as the "mercury-flotation" type, and consists essentially of a copper disk floated in mercury between the poles of a magnet, and provided

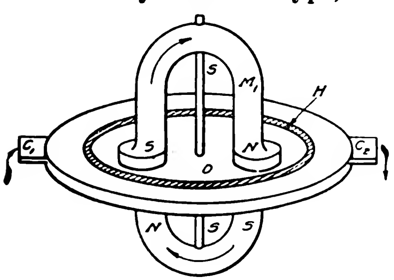

Fig. 94. Electric and Magnetic Circuits of Sangamo Ampere-Hour Meters

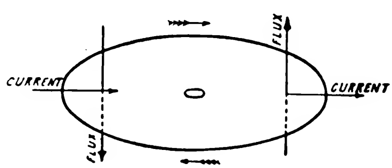

Fig. 95 Relative Directions of Currents, Magnetic Flux and Motion of Disk, Sangamo Meters

with connections to and from the mercury at opposite points. The theoretical relations of the various parts are shown in the sketch, Fig. 94. The current enters the contact C, passes through the

comparatively high-resistance mercury H to the edge of the low-resistance copper disk D, across through the disk to the mercury H and out at the contact C_2. The magnetic flux cuts across the disk on each side from N to S, making a complete circuit through M_1, and M_2. The relative directions of the magnetic flux and the current, as well as the resulting motion, are shown diagrammatically by Fig. 95. According to the laws of electromagnetic induction, if a current-carrying conductor cuts a magnetic field at right angles, a

Fig. 96. Section of Sangamo Mercury Motor Ampere-Hour Meter with Magnets and Recording Mechanism Removed

force is exerted on the conductor, tending to push it at right angles to both the current and the magnetic flux. When connected to an eddy-current damper or generator which requires a driving force directly proportional to the speed of rotation, the mercury motor-generator becomes a meter. The speed of such a meter is a measure of the current or rate of flow through the motor element, and each motor revolution corresponds to a given quantity of electricity.

Then by connecting a revolution counter to this motor-generator, a means is provided of recording the total amount of electricity in ampere hours that is passed through the meter. The method of

applying these principles in the construction of the Sangamo ampere-hour meter is shown by the sectional view, Fig. 96, in which the damping magnets and recording mechanism have been removed, though the upper part of the motor magnet, which is a laminated iron ring embedded in molded insulation—just above the copper disk—is shown plainly. In addition to making the bearing pressure independent of the weight of the moving elements, the armature disk being also immersed in mercury acts as a buffer and prevents injury to the bearings from shock.

The compensator for loss of battery capacity consists of an electromagnet shunted magnetically across the poles of the motor field magnet, its winding being in series with the discharge circuit.

Fig. 97. Ampere-Hour Meter Compensation for Discharge Rates Above Normal

Current through the exciting winding increases the magnetic flux through the motor element, thus speeding up the meter with an increase in current according to a definite and predetermined characteristic. Therefore, under very high discharge rates, the meter will register not only the ampere hours used but also those lost through excessive current or high discharge rate. The discharge curve characteristic of such a meter is shown in Fig. 97.

In the Edison battery, the transfer of active material does not take place between the electrolyte and the plates, but from one plate to the other, as in the ordinary electrolytic cell, commonly known as a primary battery. Therefore, the specific gravity of the electrolyte does not change with the state of charge and, consequently, the only direct way to measure the state of charge is with an

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Types of Instruments. The most widely used type of ampere-hour meter for electric vehicle service is equipped with a simple circular dial, as shown by Fig. 98, the dial being calibrated to read to any desired number of ampere hours per revolution. It is customary to have one revolution of the pointer represent the total available energy of the battery. Where it is desired to keep a record of the total amount of electricity either used or furnished by a battery in order to keep a check on operating economy, totalizing dials, such

Fig. 100. Sangamo Ampere-Hour Meter and Weston Ammeter in Same Case

as are used on the ordinary watt-hour meter in residence and power service, are fitted in addition. In cases where it is desired to keep a record of both charge and discharge ampere hours, two sets or duplex recording dials are fitted. With such a meter the cost of energy input in kilowatt hours is reckoned from the charge dials, while the ampere-hour output is read directly from the discharge dials.

On pleasure cars, where the presence of a large meter on the dash is not desirable for appearance's sake, an extension-dial type

of meter is employed, only the small dial face, Fig. 99, appearing. This illustration shows the direct reading pointer and the totalizing dials described above. These meters may also be fitted with the zero contact or automatic charge-stopping device, as mentioned in the article on "Charging"; but in this case the usual resetting device is not incorporated, the hand being reset simply by removing the cap and turning it with the finger against the pull of the friction drive to any desired position, where, upon release, it will be picked up again by the driving mechanism.

But in order to bring the operation of the battery under the strictest conditions of economy the single ampere-hour meter is not sufficient, a combination instrument being employed. This consists of a new type of Weston ammeter mounted in the same case as the distant dial of a Sangamo ampere-hour meter, Fig. 100. The latter shows the state of charge of the battery, while the ammeter indicates the instantaneous current value or the rate of flow into or out of the battery. A small hooded light is arranged on the dash of the machine over the instruments to illuminate the dials at night.

SUMMARY OF ELECTRIC VEHICLE INSTRUCTIONS

While the material comprising the article in Electric Automobiles is complete in itself, a series of brief questions clearly answered often forms a most valuable summary of a work and makes the article doubly useful. It is with this idea in mind that these questions and answers have been supplied. They are collected under separate heads so that desired questions and answers can easily be found.

BATTERY

Life

Q. What is the normal limiting factor of the life of a storage battery?

A. The number of discharges.

Q. What are the factors that tend to shorten the useful life of a storage battery?

A. Charging at unnecessarily short intervals; overcharging; charging at excessive rates; discharging too low; allowing to stand discharged; discharging at excessive rate; short-circuiting of individual cells or entire battery; sulphating of plates; lack of electrolyte due to failure to replenish distilled water; and corrosion.

Charging

Q. What is meant by charging at unnecessarily short intervals?

A. Recharging when only a part of the previous charge has been utilized. For example, if the vehicle has a working radius of sixty miles on a single charge of the battery, the latter should not be recharged before 40 to 50 miles have been run. It should not be put on charge again after having run only 10 to 20 miles.

Q. What is overcharging?

A. Charging for too long a time or at too high a rate.

Q. What is apt to be the result?

A. The temperature of the cells is apt to exceed the safe maximum of 110° F.

Q. Why must so much care be taken to prevent the cells from reaching or exceeding this temperature?

A. Because the heat expands the active material of the plates and, if carried beyond this point, the material will be forced out of the grids, ruining the battery.

Q. How can this be avoided?

A. By reducing the charging rate, or, if the temperature is already too close to the danger point, by cutting off the current and allowing the cells to cool before resuming the charge. If the thermometer is not handy, test with the hand; the cells should not feel uncomfortably warm.

Q. How can the length of charge necessary be determined?

A. By noting the point to which the battery has been discharged and computing the number of hours necessary to return that much energy to the battery at the normal charging rate.

Q. What is the normal charging rate of a battery?

A. This differs with the capacity and type of cell and a plate or card giving it usually will be found on the car.

Q. Is this charging rate uniform throughout?

A. If there is ample time in which to charge at a uniform low rate it is preferable, but for ordinary charging, when it is desired to have the car ready for service again quickly, there is a starting charge rate and a finishing rate.

Q. How can the proper rate be computed for a uniform charge?

A. An estimate of the amount of current necessary to charge the battery fully must be made and this quantity divided by the number of hours available. For example, if 84 ampere hours are necessary and the time available is 12 hours, as overnight, the average rate will be 7 amperes.

Q. What other factors influence a uniform charge?

A. If the charging circuit has a constant potential, or a mercury arc rectifier is employed, the charging rate will automatically decrease as the charge progresses, owing to the rising voltage of the cells.

Q. How high can the average starting rate be for an electric-vehicle battery?

A. If the battery is fully discharged or down to at least 75 per cent of its capacity, it may be anything up to 35 amperes which is about the maximum capacity of the average garage charging apparatus. The battery may be put on charge with this starting rate even if only half discharged, but the rate will have to be lowered much sooner.

Q. Is it good practice to charge a battery when less than half discharged?

A. No. At least 50 per cent and preferably 75 per cent of its capacity should be utilized before recharging.

Q. What determines the end of the starting period of the charge?

A. The cells begin to gas freely.

Q. What is meant by "gassing", and is it injurious to the battery?

A. In the conversion of lead from one form to another by the passage of the charging current, hydrogen gas is evolved. When charged at too high a rate or for too long a time the gas is generated so rapidly that it bubbles out as if the electrolyte were boiling. This is termed "gassing freely". Gassing in itself is not injurious to the battery but it is an indication that conditions which will cause injury, i.e., excessive charging and overheating, are present.

Q. When on charge at the starting rate, what should be done when the cells begin to gas freely?

A. Reduce the charging rate to the finishing rate.

Q. How low should the finishing rate be?

A. Generally speaking, it should never exceed 10 amperes.

It is good practice to make it as much lower than this as possible, consistent with completing the charge in the time available.

Q. Does the use of a high starting rate tend to injure the battery?

A. Not if the rate is lowered to the finishing limit as soon as the cells gas freely.

Q. Which is preferable, the employment of a low average rate over a long period, or a high starting and low finishing rate?

A. Other things being equal, the lower the charging rate used, the longer will the life of the battery be. The adoption of starting and finishing rates is simply to cut down the time of charging.

Q. How can the charge be hurried safely?

A. Start the charge at the maximum capacity of the charging apparatus and as soon as the gassing point is reached, reduce it by successive steps down to the normal finishing rate, bearing in mind that the gassing point voltage must not be exceeded at a current rate higher than 10 amperes.

Q. What should the charging rate be for overnight or unattended charging?

A. The starting rate should be such that as it falls due to the rise of the battery voltage, it will reach a minimum of 6 to 10 amperes when the charge approaches completion. With a mercury arc rectifier or the usual incandescent lighting circuit (constant potential) the proper starting rate ordinarily will be 18 to 20 amperes. With some small motor-generators it may be as high as 35 amperes.

Q. Is it ever permissible to overcharge the battery?

A. It is beneficial to overcharge the battery at regular intervals. Once a month the regular charge should be followed by an overcharge at the finishing rate until the specific gravity of every cell has stopped rising. (See Hydrometer Readings.)

Q. When a battery is to remain idle for some time, how should it be treated?

A. Give it an overcharge before putting out of service and after this charge flush the cells right up to the covers with distilled water to allow for evaporation and absorption of the acid by the plates. Give it a freshening charge at the finishing rate once a month. Before putting in service again discharge the battery and then overcharge it.

Q. Will a battery give its usual capacity upon being put back in service after a period of idleness?

A. No. It may not reach its usual maximum until it has had several charges and discharges.

Q. What precautions should be taken before putting a battery on charge?

A. Lock the control lever in the *off* position, open the battery vents, and lift the hoods to give as much ventilation as possible; see that there is no possibility of any loose pieces of metal, such as tools, falling on the cells and that no naked flame or spark is brought near it. Do not turn on the lamps or ring the bell with the charging current on, as the increased voltage may burn them out.

Boosting

Q. What is meant by "boosting" the battery?

A. Giving it a short charge at a very high rate to increase the daily mileage radius of the vehicle.

Q. What are the possible safe charging rates that may be employed in boosting?

A. Any current rate that the cells can absorb without gassing is not injurious. See Table VI, page 103.

Q. Can the Edison battery be boosted the same as a lead-cell battery?

A. This is permissible at even higher rates, as the safe temperature limit is 115° F. See the table on page 98.

Q. What are the limitations on charging generally?

A. The cells must never be allowed to gas freely or to become too warm without reducing, or if necessary, stopping the charge to allow them to cool.

Methods of Charging

Q. What methods of charging electric vehicles are usually employed?

A. In garages that maintain more than one or two electrics, a charging panel capable of charging several cars at once is employed. This is either connected with the lighting mains where direct-current service is available, or is fed by a motor-generator where the service is alternating. For taking care of but one or two cars a mercury arc rectifier for the alternating current is sometimes used.

Q. Is the chemical type of rectifier ever employed for this purpose?

A. Its efficiency is too low to make it practical for anything but the small batteries of the lighting-and-starting systems of gasoline cars.

Q. In an emergency, can a vehicle battery be charged from direct-current mains without the use of special charging apparatus?

A. This may be done by employing a bank of lamps in series-multiple with an ammeter and a double-pole fused switch on the mains. One wire is led directly from the switch to the charging connection on the car; the other is connected first to one side of the ammeter; from the other side of the ammeter a connection is made to one side of the multiple lamp circuit. A wire from the other side of the lamps completes the charging circuit. As all cars are provided with a charging socket which will take only a special plug, it may be necessary to connect the wires directly to the battery terminals. Sufficient 32-c-p. carbon-filament lamps must be employed to give the proper amount of current; a smaller size may be used just as well but more of them will be required. At least ten of the larger size will be necessary as they consume approximately 1 ampere each, thus giving a charging current of 10 amperes. For the higher rate permissible for starting the charge, twenty to thirty of these lamps may be necessary. When the battery begins to gas on this rate, some of the lamps must be removed, to cut down the current. If a rheostat is available, it will be found much more convenient; it should be connected in series with the ammeter in place of the bank of lamps.

Q. What precautions must be observed in emergency charging?

A. Only direct current can be used; its polarity must be determined so that the positive side of the circuit is connected to the positive terminal of the battery. This can be done by inserting the bared ends of two wires connected to the mains in a glass of water, keeping the wires separated as much as possible. The wire from which the greatest amount of gas rises is the negative. As the charging plug probably will not be available, care must be taken to see that the wires are connected to the battery terminals so that all of the cells are in series. To do this it will be necessary to trace

the connections between the two sections of the battery under the front and the rear hoods of the car. Thirty-ampere fuses should be provided at the switch.

The hoods must be lifted and the vent plugs of all the cells opened. Unless a hydrometer or a voltmeter is available for testing the state of charge, charging must be discontinued when the cells begin to gas freely after the current has been reduced to the finishing rate, which should not exceed 10 amperes. In case the car is provided with an ampere-hour meter, this may be relied upon to indicate when the battery is sufficiently charged. The instructions regarding direct current and its polarity naturally apply to charging under any conditions, but when the regular charging panel and the charging-plug connection are available, no special precautions are necessary, as the charging plug can only be inserted in its socket the right way.

Discharge

Q. How far can a storage battery be discharged safely?

A. Its voltage should never be allowed to drop below 1.170 volts per cell.

Q. Has the rate of discharge any effect on the capacity of the battery?

A. The capacity of the battery will fall off as the discharge rate increases. For example, a 100-ampere-hour battery will give 5 amperes for 20 hours but it will not give 50 amperes for 2 hours.

Q. How far should the battery be discharged before recharging?

A. At least 50 per cent of its capacity, and preferably 75 to 90 per cent, provided it is to be recharged as soon as this point is reached.

Q. Why is a discharge at a very high rate such as is caused by a short circuit injurious?

A. The chemical reconversion of the active material of the plates in producing the current takes place so quickly that their temperature rises abnormally, causing them to "buckle".

Q. Is it ever necessary to discharge the battery down to zero?

A. Its condition will be improved if discharged to this point at intervals of about a month.

Q. How can this be done?

A. Connect the battery terminals through a rheostat so that the discharge will be limited to the normal slow rate. This is usually done after the battery has been discharged in service down to 80 to 90 per cent of its capacity. Immediately after reaching 1.170 volts per cell on discharge, it must be recharged.

Q. Why must a battery never be allowed to stand discharged?

A. In this condition what is known as "local action" between the plates takes place and they become sulphated.

Q. What is sulphating?

A. The lead sulphate evolved during the discharge will harden on the plates if the battery is allowed to stand discharged.

Q. How can a sulphated battery be brought back to good condition?

A. By continuous charging for a long period at a low rate, but at a higher voltage than usual, as the latter tends to break down the coating of sulphate on the plates.

Q. What indication is there of sulphating, and how can it be determined to what extent it has taken place?

A. The cell otherwise being in good condition, it will be indicated by loss of capacity, and the degree to which the latter has fallen off will afford a measure of the extent of the sulphating.

Q. How long must the charge be continued to remedy this condition?

A. Depending on the extent to which the plates are covered with the hard coating of white lead sulphate, it may require anywhere from 24 hours to a week or more.

Q. Why cannot a battery be allowed to stand idle without being recharged at regular intervals?

A. Because the cells tend to discharge when standing idle, owing to the unstable nature of the chemical compounds which represent the stored energy.

Electrolyte

Q. Of what does the electrolyte of a storage battery consist?

A. A solution of distilled water and chemically pure sulphuric acid.

Q. How is it mixed?

A. By using a porcelain, glass, earthenware, or wooden vessel and pouring the acid into the distilled water very slowly, as the chemical combination of the acid and water evolves a great amount of heat.

Q. Why should water never be poured into the acid?

A. It will spatter about with explosive force and the acid is extremely corrosive, causing serious burns wherever it touches.

Q. How is the proper proportion of acid to water to form electrolyte determined?

A. With the aid of the hydrometer. The proportions of acid to water are 1:4¾ for 1.200 sp. gr. and 1:3 for 1.275 sp. gr. See Hydrometer Readings.

Q. Is it ever necessary to add electrolyte to the cells?

A. Very rarely. A battery should go from one washing to another without any necessity of adding electrolyte.

Q. How should losses by evaporation be made up?

A. By the addition of distilled water, rain water, or melted artificial ice.

Q. How often should distilled water be added?

A. The height of the electrolyte over the plates should be noted every time the battery is charged. It should always be kept ¼ to ½ inch over the plates.

Q. Does the temperature of the electrolyte have any effect on the battery action.

A. It might have. Extremes of temperature affect the specific gravity of the electrolyte and should be avoided.

Q. Why should ordinary water or ordinary commercial acid not be used for electrolyte?

A. Owing to the impurities they contain which will affect the active material of the plates.

Q. How can the presence of impurities in the electrolyte be determined?

A. By the odor noticeable on charging and by the discoloration of the positive plates. Hydrogen gas has a distinctive odor which will be recognized readily after a few times.

Q. Is the electrolyte of the Edison cell the same as that of the lead cell?

A. No. It is an alkaline solution of potash and water.

Q. Is it ever necessary to add new electrolyte to an Edison cell?

A. Nothing but distilled water should be added.

Voltage

Q. Why is it necessary that the charging-current voltage should exceed that of the battery?

A. Because the voltage of each cell increases as the charge progresses and unless the charging current were at a higher voltage it could not overcome that of the battery. The battery would then "reverse" until its voltage equalized that of the charging current.

Q. How much should the charging voltage exceed that of the battery?

A. See Table II, page 85.

Q. Is the voltage of the Edison battery the same as that of the lead type?

A. No. For charging voltages, see the table on page 97.

Q. Is the voltage a good indication of the condition of the cell, and how does it vary?

A. Next to the specific-gravity reading, the voltage affords the best test of condition. The voltage varies from 1.170, when completely discharged, to 2.55 volts per cell, when fully charged.

Q. How must voltage readings be taken?

A. Only when the battery is either charging or discharging. Readings with the battery idle are valueless.

Q. Does the voltage vary with conditions other than that of the state of charge?

A. Temperature and the age of the cell will cause a variation. The higher the temperature and the older the cell, the lower the voltage will be for the same state of charge.

Q. Which affords the better indication of the state of charge, the voltage or the specific gravity of the electrolyte.

A. The specific gravity of the electrolyte. See Hydrometer Readings.

Hydrometer Readings

Q. What is a hydrometer, and how is it used?

A. It is an instrument for determining the specific gravity of

a liquid. For storage-battery use, it is combined with a syringe so that some of the electrolyte may be drawn off for a test.

Q. What is the specific gravity of a liquid?

A. Its density as compared with distilled water which is unity in the specific-gravity scale.

Q. Are hydrometers ever calibrated in any other standard?

A. Yes, the Baumé scale. See Table IV, page 93, for comparative readings.

Q. Why is the hydrometer test employed for the storage battery?

A. Because it affords the best test of the condition of the cell.

Q. What should the electrolyte test when the cell is fully charged?

A. 1.270 to 1.280.

Q. How low may it be permitted to run?

A. As low as 1.250 in a fully charged cell.

Q. How should the test be made and how often?

A. By withdrawing sufficient of the electrolyte in the syringe to float the hydrometer. Note the reading and return the electrolyte to the same cell; test each cell the same way and never put the electrolyte from one into another cell. The test should be made once every two weeks.

Q. How close should the readings of the different cells be to be considered uniform?

A. Within 25 points on the scale; i.e., no cell in a battery should be below 1.250 or above 1.275 when it is fully charged.

Q. What do the various readings indicate?

A. A specific gravity of 1.150 indicates that the battery is practically discharged; below 1.150, completely discharged or "run down"; above 1.200, more than half charged.

Q. Is it ever permissible to bring up the specific gravity of a cell by adding electrolyte?

A. No. It will do no good and is apt to cause great harm. The only way it should be raised is by charging the cell.

Q. When some cells have a much lower reading than others, what should be done?

A. Such cells first should be charged separately at a low rate. If its specific gravity increases on charge, it simply indicates that the cell has been discharged lower than the others and needed

additional charging. When it has been brought up to the others, the whole battery may be charged.

Q. In case the electrolyte of such a cell does not increase on charge and the cell does not increase in temperature, what is the trouble?

A. The gravity of the electrolyte has been lowered by excessive additions of water to compensate for leakage or similar cause.

Q. When putting new electrolyte in cells after washing them out, what precaution must be observed?

A. The new electrolyte must be of the same specific gravity as the old.

Q. Can the specific-gravity test be employed with the Edison cell?

A. No. As its electrolyte does not vary in this respect with state of charge, the voltage test must be employed.

Q. Does the temperature affect the hydrometer reading?

A. It will be lower at low temperatures, and should be watched rather carefully. Note the variation between 30° F. and 100° F. in Table III, and study its temperature effect in Part I.

Battery Jars

Q. Of what are the battery jars composed?

A. Usually hard rubber in the case of the lead cell, and stamped steel for the Edison cell.

Q. To what faults are lead-cell jars usually subject?

A. Leakage caused by not having the battery firmly clamped in place. This permits movement of the cells and one or more of them is apt to become cracked.

Q. How can a leaky jar be recognized?

A. Leakage due to cracks in the jar usually is very gradual, but it will be noted that a leaky cell requires refilling oftener than the others. After a short period its specific gravity will differ from that of the others, owing to loss of electrolyte.

Connectors

Q. How can the lead straps and pillars forming the connectors be kept in good condition?

A. By wiping them and the tops of the jars dry with a clean rag after charging. If the battery has "gassed" strongly, dip the rag in a solution of ammonia and water as the gas carries with it

a fine spray of electrolyte and the acid will cause corrosion unless counteracted. A good preventive of this corrosion is to smear the entire tops of the jars and the connectors with a light coating of vaseline.

Q. When a cell has to be disconnected for any reason, how is it reconnected to the remaining cells?

A. By burning the lead strap together if it has been cut, or burning it to the pillar.

Q. In case the lead strap cannot be burned at the time, is it ever permissible to use any other connector?

A. Heavy copper wire or a strip of copper or brass may be soldered or bound on, but it should be removed as soon as possible.

Washing the Battery

Q. What is meant by "washing" the battery, and why is it necessary?

A. Washing a battery involves cutting the cells apart, washing the elements and the jars, and reassembling with new separators and new electrolyte. It is necessary to prevent the accumulation of sediment in the mud space of the battery from reaching the bottoms of the plates; this sediment is the active material shaken from the plates and, as it is a good conductor, it would cause a short circuit and probably ruin the battery.

Q. What are the elements of a battery?

A. The positive and negative groups of plates. The positive is a dull red and the negative a grayish color.

Q. How often is it necessary to wash a battery?

A. This will depend on the type of jar and the age of the elements. With the modern style jar having an extra deep mud space, it will probably not be necessary to wash the battery until it has seen two or three seasons' service. With the older form in which the space allowed for sediment is much less, washing may be necessary once a season. As the battery ages it will be necessary to wash it oftener.

Q. What other causes besides the type of jar and age influence the frequency of washing?

A. The treatment the battery has received. If it has been abused, active material is forced out of the plates much sooner.

Q. How can the necessity for washing be determined?

A. The presence of a short circuit in one of the cells. Cut out the cell and open it. If the short circuit has been caused by an accumulation of sediment, the others are in practically the same condition and will soon become shorted also.

Q. How is a battery washed?

A. By cutting the cells apart, unsealing them, and lifting out the elements, which immediately should be immersed in a wooden tub of clean pure water. The separators are then lifted out and the positive and negative groups of plates separated and marked so that they may be put back in the same cells. Before disposing of the old electrolyte, its specific gravity should be noted. The plates should be washed in copious running water for several hours, never allowing their surfaces to become exposed to the air. Reassemble with new separators, fill jars with fresh electrolyte of the same specific gravity as that discarded and keep elements under water until ready to place in jars, which should then be sealed and the lead connectors burned together again. Give a long slow charge after reassembling.

Q. Why should lead connectors be employed, and why is it necessary to burn them together?

A. Any other metal will quickly corrode. Burning is necessary to make good electrical connection, except where bolted connectors are fitted.

Q. Is it ever necessary to wash out an Edison battery?

A. No. The cells are permanently sealed as the active material cannot escape from the containers.

Efficiency

Q. What is the efficiency of the storage battery?

A. About 80 per cent under favorable operating conditions. See Fig. 11, page 27.

Q. What affects the efficiency of the battery?

A. Sulphating; very low temperatures; loss of electrolyte; dropping of active matter from the plates; partial internal short circuit between the plates; use of impure water; failure to keep properly charged and to discharge fully at regular intervals; and undercharging and overcharging.

Q. Is the efficiency of the battery affected by temperature changes?

A. When the weather is very cold, the efficiency of the battery is cut down substantially, and this will be very perceptible by the reduced mileage available on a charge on the coldest days of winter.

Q. What instruments should be kept handy for testing the battery?

A. A hydrometer syringe, a good thermometer, and a low-reading voltmeter.

Q. What other causes will tend to reduce the efficiency of the battery?

A. The presence of impurities in the electrolyte caused by using ordinary water or commercial sulphuric acid.

POWER USAGE

Motor Commutator

Q. What attention is necessary to keep the motor of an electric vehicle in good running condition?

A. The commutator and brushes should be inspected at regular intervals. If the commutator is discolored and dirty, it should be wiped off with a clean rag moistened in good lubricating oil but very little of it.

Q. If this does not remove the discoloration, what should be done?

A. Take a strip of No. 00 sandpaper, the width of the commutator, jack up one rear wheel, run motor slowly on first speed, and hold sandpaper to commutator. If this does not smooth commutator off to a uniformly clean surface, it will be necessary to remove armature and take a light cut off the commutator in the lathe to remove any depressions or ridges. Smooth down with sandpaper after turning off.

Q. Is the commutator discolored when it shows a bluish metallic tinge?

A. No. It is then in the best running condition and should not be touched with sandpaper. Discoloration is black and usually consists of an accumulation of dirt and oil, or it may be caused by sparking at the brushes.

Q. Does a commutator need oiling?

A. No more than can be applied by wiping with a clean oiled rag.

Q. When a commutator is worn down, what should be done with it?

A. Turn down in a lathe and smooth with sandpaper, as above.

Brushes

Q. What is the cause of sparking at the brushes?

A. Uneven contact on the commutator; weak brush-holder springs; an accumulation of carbon dust and oil on the commutator; running the motor under excessive overload; or a short-circuited or grounded armature coil.

Q. What is the usual remedy?

A. "Sand in" the brushes, by placing a strip of No.00 sandpaper on the commutator, face up. Jack up a rear wheel and have an assistant turn it by hand to turn the motor over. The brush should be sanded down to a close and uniform fit over its entire surface at the point of contact with the commutator. Proceed in the same way with each brush. If, with a clean and smooth commutator, this does not remedy the trouble, see if the brush-holder springs are holding the brush firmly against the commutator. Never use coarse sandpaper or emery.

Q. What does excessive sparking at adjacent commutator bars indicate?

A. A short-circuited or open armature coil.

Q. How often should brushes be replaced?

A. When they have worn down to a point where the spring can no longer press them against the commutator properly; this rarely will be oftener than once in a season.

Q. Is it permissible to replace worn brushes with any standard carbon brushes that will fit the holders?

A. The motor will operate with such brushes but this should not be done if it can be avoided, and then only temporarily—new brushes supplied by the maker of the car being inserted as soon as they can be obtained.

Q. Is a "carbon brush" a fixed quantity, or do they differ particularly?

A. There are hundreds of different carbon brushes and probably no two are exactly alike; their resistance and their hardness both differ and they are made in a great variety of shapes to fit different holders, so that no brushes except those supplied by the maker of the car should be used as replacements. Trouble is bound to follow, otherwise.

Controller

Q. What is the function of the controller?

A. To vary the amount of current supplied to the motor and thus vary the speed of the car.

Q. How many types of controllers are there in use on electric cars?

A. Two general classes: one in which the operation is manual, i.e., the actual closing of the various switches representing the different steps in the control is carried out by moving a lever by hand; while in the other, known as a magnetic controller, shunt circuits operated by push buttons are utilized to energize electromagnets which in turn close the actual switches.

Q. What faults are to be looked for in the manually operated controller?

A. Poor contact of the switch fingers, due to loosening of the holding screws or weakening of the springs; burned contact fingers or segments, usually due to the same causes.

Q. How can they be corrected?

A. By cleaning with fine sandpaper and if the finger does not make uniform contact over its entire surface, bending slightly to make it do so. These fingers usually have curved up ends which cause them to engage the segments of the drum and stay in the position to which they are moved. Care must be taken in bending them, not to bend down too far, as the finger is then apt to catch on the segment or contact plate instead of riding over it. If the finger is making good contact all over its surface, it will not be possible to insert a thin piece of paper between it and the segment; nor, if inserted by lifting the finger, can the paper be pulled out. It should hold fast and tear when an attempt is made to draw it out from under the finger. There is danger of short-circuiting if the adjustment of the fingers is not carried out properly.

Q. What should be done before attempting to do any work on the controller?

A. Disconnect the battery and wrap the terminals of the cables with friction tape so that they cannot make electrical contact with any metal parts.

Q. What faults are apt to occur with the magnetic type of controller?

A. Broken or loose connections either at the push-button end of the control or at the electromagnets. The switches actuated by the magnets are usually fitted with carbon contact blocks which will give service for a long while without any attention. In time, however, the faces of the blocks are likely to become burned or pitted and will need squaring up.

Q. When the car refuses to run, the battery being in good condition, is the controller necessarily at fault?

A. This does not always follow, as there may be a broken connection between the battery and the controller or between the latter and the motor; or the motor brushes may not be making contact with the commutator.

Q. In case the car will run on certain speeds but not on others, what is the cause?

A. Either the contact finger representing the speed in question, or some of the contact fingers below it, i.e., in the order of closing the circuit, may not be making contact. Each contact finger is not an independent unit but often depends upon those below it in the order of closing the circuits. For example, if a car having five speeds will run on speeds 1, 2, and 3, but not on speeds 4 and 5, the trouble may be due to poor contact of fingers 2 or 3.

Q. When the car will run forward but not backward, what is the cause?

A. Usually failure of the reverse switch to operate, and this naturally is the case also where it will run backward but will not run forward.

Q. What is a reverse switch, and how does it operate?

A. It is a double-pole double-throw switch with cross-connections; i.e., if the connections at one side of the switch are positive-negative, they will be negative-positive on the other side. By shifting the switch from one set of contacts to the other, the polarity

of the battery with relation to the motor is altered and the direction in which the current passes through the motor is reversed. This will cause it to start in the opposite direction to which it would run with the switch in the other pair of contacts. Once started, the operation of the motor is the same, regardless of the direction in which it is running.

Q. Does the controller provide as many speeds backward as forward?

A. Not as a rule; it is neither necessary nor safe to run the car backward at high speed, so that fewer reverse speeds are provided.

Q. Where is the reverse switch usually located?

A. In some cases, it is combined with the controller and this is particularly the case with the magnetic type; in others, it is entirely separate. For example, on the Ohio, the reverse is in the contactor box of the controller; on the Anderson, it is located at the foot of the control mast and is accessible from the outside by the removal of a small plate.

Q. Is it necessary to lubricate the controller?

A. The bearings should be oiled at regular intervals the same as any other moving parts, but owing to their limited and slow movement but little oil is required. The contact fingers should also be lubricated; in some cases, as on the Anderson, special provision is made for this in the form of oil pads which should be saturated with oil once in six months.

Instruments

Q. What are the functions of the ammeter and voltmeter on the electric vehicle?

A. The ammeter has a double reading scale, the needle moving to the left to show the amount of current going into the battery on charge, and to the right to indicate the amount of current used by the motor in driving the car. The voltmeter indicates the total voltage of the battery and shows the condition of charge, as the voltage accurately checks the amount of energy in the battery.

Q. When should such readings be taken?

A. Only when the battery is being charged or discharged, as in running the car. Instrument readings with the battery idle are of no value.

Q. What does an erratic jerky movement of the voltmeter needle indicate?

A. The presence of a loose connection which is making contact at times and at others is being shaken loose.

Q. What is the trouble when the voltmeter gives no reading?

A. A break in the circuit between the battery and the instrument.

Q. What should the voltmeter read when the battery is fully charged?

A. The equivalent of 2.55 volts per cell while the battery is charging. The moment the charging circuit is opened, the voltage will drop off somewhat. For a 40-cell battery this reading should be 100 volts or a little over at the completion of the charge and before the charging circuit is broken. When the needle indicates only 68 volts, the battery is exhausted; the reading should not be allowed to go below 76 volts for a battery of this number of cells, and in the same proportion for a greater or lesser number, i.e., the equivalent of 1.9 volts per cell.

Q. Are the instruments liable to defection in service?

A. The vibration and pounding due to running over uneven pavements are extremely severe on a delicate instrument. If the ammeter fails to register when the vehicle is started, examine the connections; see that the needle has not become bent so as to bind it, or see whether it appears to have been shaken out of its bearings, though this rarely will happen. To make certain that the instruments are correct, they should be checked at least once a season by comparing with a standard instrument and any variation found allowed for in making subsequent readings. This is particularly important with the voltmeter on which a slight variation would give a misleading indication of the state of the battery, as a difference of two or three volts would make it appear that it was fully charged before this was actually the case, or nearer exhaustion than in reality.

Q. When the voltmeter needle drops to zero and the car will not run, what is the cause?

A. Trouble in the battery such as a short circuit, or a break in the battery wiring such as would be caused by a broken connection. See that the battery is properly connected and all connections in the

circuit are clean and tight. Examine the level of the electrolyte in all the cells and replenish with distilled water, if necessary. Look for cracked or broken jars where electrolyte is very low in a cell.

Q. When the voltmeter reads normally, but the ammeter does not register and the car will not run, what is the trouble?

A. Most of the late-model electrics are provided with a cut-out operated by the brake; see that the brake is released all the way and that the cut-out is operating to close the circuit. Examine the contacts of the latter and all the contacts and connections of the controller. Do the same for the reverse switch. Note whether brushes are making good contact with the commutator.

Q. When the ammeter reading is very high, but the car will not start, what is apt to be the cause?

A. The brakes may be binding or something may have gone wrong with the universal joint or with the gears or bearings of the differential. Jack up one wheel and see if it can be turned freely by hand. If it cannot be turned and the brakes are free, remove the rear axle and examine the universal joint, gears, and bearings.

Q. If the car runs, but the ammeter reading is unusually high, what is the trouble?

A. The brakes may be dragging; see that they release fully when the pedal is all the way back. See that the front wheels are properly lined up; they are usually given a camber of $\frac{1}{4}$ to $\frac{3}{8}$ inch, i.e., when viewed from the front they apparently "toe-in". A plumb line held at the top of the tire should strike the floor that distance away from the tire. The front wheels may not be in line with the rear wheels; this usually is caused by running against a curb or dropping into a bad hole, which bends the steering connections. If the wheels do not line up properly, adjust the steering connections; it may be necessary to bend a part back to bring the wheels into line, and this should be done cold. Examine the differential and all bearings and driving connections to see that they are properly lubricated. See that the tires are properly inflated and that only "electric" tires are fitted. (See Tires.)

Q. When the reading of the ammeter is normal, but the speed and mileage are low, what is the trouble?

A. The battery or the motor may be at fault. (See Low Mileage.)

Q. What is considered a normal ammeter reading?

A. On smooth hard pavements and in good weather, a car provided with a 40- or 42-cell battery should draw about 30 amperes on its highest regular speed after it has finished accelerating and is running easily. With a battery of a smaller number of cells, this will be higher. It will also be much higher on the accelerated speed which is only designed for employment in emergencies.

Q. Are any instruments other than the voltameter ever employed?

A. Many cars are fitted with ampere-hour meters which show how many ampere-hours have been put into the battery on charge and how much has been taken out in running. They give a direct reading of the amount of energy available in the battery at all times.

Q. To what faults are such instruments liable?

A. Broken connections, loose or dirty connections, or a broken wire are the only causes of failure that can be remedied in the garage. If the instrument is not working properly, due to any other cause, it will be necessary to return it to the makers.

Wiring

Q. Is trouble often experienced with the wiring of an electric vehicle?

A. Very rarely; the cables are usually of ample size to carry the loads for which they are designed, i.e., the lamps or the motor, and they are protected by steel armor in the majority of instances. On older cars on which adequate protection to the wiring was not always the rule they may be found to have suffered at times from mechanical injury.

Q. What faults are most apt to occur in the wiring?

A. Loose or broken connections at the terminals, whether at the motor, battery, controller, or reverse switch. This is due simply to the vibration and jolting, and when trouble is experienced in the running of the machine on the different speeds, the various connections should all be examined, first, however, disconnecting the battery as mentioned for inspection of the controller.

Q. Are there any grounded connections on the electric vehicle, as in the case of lighting-and-starting systems on the gasoline car?

A. No. All circuits are of the two-wire type and considerable

care is taken to insulate all cables and wires from the chassis of the machine. Frayed ends of stranded cables may sometimes cause a ground which will announce its presence by blowing the fuse on that particular circuit.

Q. Is there any way of detecting the presence of loose connections except by inspection?

A. A jerky movement of the voltmeter needle indicates that the circuit is being made and broken at intervals, as would be caused by the vibration at a loose connection.

Fuses

Q. Where are the fuses located, and what circuits on the electric car are protected by fuses?

A. Usually on a small panel board or junction box on the forward face of the dash under the hood; sometimes under the floor boards (consult the wiring diagram). Only the lamp circuits are protected by fuses, as the load imposed on the motor in starting the car in heavy snow or similar bad conditions will often cause the ammeter needle to go the limit of its travel, so that fuses on the power circuit would not be practical.

Q. When a fuse blows, what does it indicate?

A. Usually that a lamp has burned out and in doing so has caused a temporary short circuit on that line. This may also be caused by a ground or short circuit in the wiring, generally at the lamp socket, as the wires themselves are usually well protected from injury. Before replacing a burned-out lamp, inspect the terminals and connections.

Q. If the same fuse blows repeatedly, where should the cause be sought?

A. Should inspection show that none of the connections at the lamp or the junction box are at fault and the wiring is intact, see if the battery connections are properly made, if the battery has been overhauled. See that the proper type of lamp is being used for replacement and that it is of the proper voltage.

Lamps

Q. What is the voltage of the lamps usually supplied on the electric car?

A. Generally that of the total nominal voltage of the battery,

i.e., on a car having a 40-cell battery, 80-volt lamps would be used. On cars having what is termed a double-voltage system (Ohio), the battery being coupled in two units of 20 cells each connected in parallel to give certain speeds, instead of employing a resistance, 40-volt bulbs are used.

Q. Why should the lamps never be lighted while the battery is on charge?

A. The excess voltage may burn them out or blow the fuses.

Q. What causes one lamp to burn much brighter than the other?

A. A bulb of higher voltage may have been used as a replacement in one socket, or one of the bulbs may be much older than the other. The filament increases in resistance with age so that it takes less current and gives correspondingly less light.

Q. If a lamp fails to light, what is the cause?

A. The fuse on its circuit may have been blown out, or the lamp itself may not be making good contact in the socket; the wiring may have become grounded or short-circuited, usually at the lamp socket. The bulb may be burned out, or its filament broken.

Low Speed and Mileage

Q. What are the chief causes of low mileage per charge?

A. (*Battery*) The battery may not have been fully charged before starting out; the level of the electrolyte in the cells may be too low, or there may be a leaky jar. The battery may have lost a considerable percentage of its efficiency through abuse or age, or it may be new. Full mileage is never obtained on the first run or two with a brand new battery or a battery that has just been overhauled; it will not give its normal output until it has been charged and discharged four or five times. The battery may not be connected up properly; check with the wiring diagram.

(*Motor*) See that the commutator is clean and bright, that the brushes are making good contact with it over their entire surface, that they have not been worn down too far and that the springs have sufficient tension to keep them firmly pressed against the commutator. See that all connections are clean and tight. Examine the armature connections and see that none have become broken or short-circuited; this will usually be indicated by the condition of the commutator and is at best a rare cause of trouble.

(*Brakes*) See that the brakes are properly adjusted and are not rubbing against the drums at any point when fully released. This will usually be indicated by a high ammeter reading.

(*Lubrication*) Neglect to keep the differential housing filled to the proper level with the right kind of oil (worm drive), or with the proper grease (bevel gear drive), and failure to lubricate the motor and wheel bearings will increase the draft on the battery and cut down the mileage. The use of grease in the differential of the worm drive or the employment of a heavier grease than that recommended by the maker for a bevel drive will do likewise.

(*Controller*) Note whether all the contact fingers of the controller bear firmly against the segments and whether there is any arcing at the contacts when they are operated. Clean and adjust as explained under "Controller". Examine reverse switch or switches (duplex drive) for the same causes of trouble.

(*Tires*) Underinflated tires or the use of a "gasoline" type of tire, even on but one of the wheels, will cut down the mileage very perceptibly. Nothing but electric-car tires should ever be employed, and if tires intended for a gasoline car have been fitted, replace them.

(*Driving*) Low mileage is due as frequently to improper handling of the car as to any other cause. Excessive use of the accelerator speed causes an abnormally heavy draft on the battery and the mileage will be considerably reduced. Failure to take advantage of grades to coast, or to shut off the power sufficiently in advance of a stopping place to permit the car to come to a halt without more than a gentle pressure on the brake pedal, will do likewise. Attempting to start before fully releasing the brakes will also waste a great deal of power, if it does not result in badly burning the commutator or burning out the armature windings. Making an unusual number of stops and short runs in a day's use will cut down the mileage.

(*Weather Conditions*) The normal mileage per charge is based on favorable road conditions and, as the latter are affected by bad weather, the car will not run as far on a charge in rain or snow as in dry weather. Wet pavements cause the driving wheels to slip in starting, thus causing a loss of power, while the presence of snow or mud on the streets will call for a greatly increased amount of power to cover the same distance.

DOBLE STEAM CAR WITH TOURING BODY

Courtesy of General Engineering Company, Detroit, Michigan

STEAM AUTOMOBILES

INTRODUCTION

Development of Steam Engines. That steam could be employed to produce mechanical motion was first noted in history about 130 B. C., but it was not until the seventeenth century that it found practical application in the industries. The developments were comparatively slow, however, until James Watt (1769) developed his engines to a point where they employed practically all the principles of the modern double-acting, condensing steam engine.

With these rapid inprovements came the idea of using the steam engine as a means of road locomotion, and in the opening years of the

Fig. 1. Early Steam Carriage Built by Cugnot (France) in 1770

nineteenth century such machines were actually built and known as "road locomotives", Fig. 1. These machines might be called the forerunners of the steam automobile, although structurally they more nearly resembled the later traction engines. Bad roads, great weight, public opinion, and the development of railroads caused road locomotives to drop out of sight until the real coming of the automobile almost a hundred years later.

In the meantime the steam engine—both stationary and locomotive types—had reached a high state of development and hence many of the early automobiles carried this type of power plant.

Later improvements were made and are still being made along lines peculiar to steam automobile construction. Although during the last few years the steam car has not kept pace in numbers with other types of automobiles, it has certain characteristics, such as strong pulling powers at low speeds, capacity for big overloads, and ease in driving on the road, which make it especially useful under some conditions, the success of the London steam omnibuses being a good example.

CHARACTERISTIC FEATURES OF STEAM CARS

In the modern steam automobile the power plant is made up of the same general units as make up the stationary power plant, the only difference being the extreme compactness necessary and the development of the great flexibility required to meet the sudden changes in load conditions. With both plants there must be a supply of fuel, a means of burning it, a boiler or steam generator, a supply of water, an engine, and various means of controlling the amounts of fuel, water, and steam.

Location of Engine. With steam automobiles there is no uniformity of practice as to the placing of the different units in the

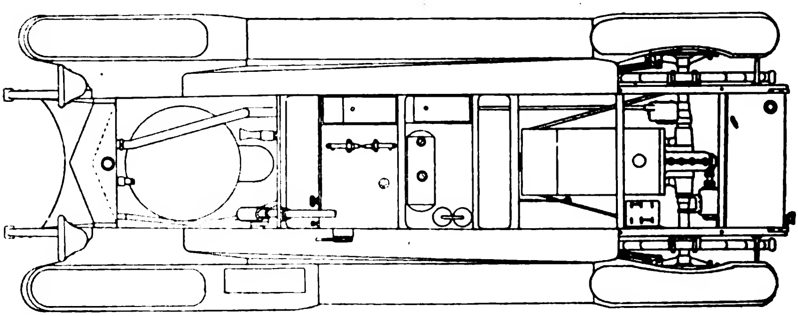

Fig. 2. Plan View of Stanley Steam-Car Chassis
Courtesy of Stanley Motor Carriage Company, Newton, Massachusetts

running gear or chassis. For instance in the Stanley, Fig. 2, the boiler is under a hood in front of the driver and the engine is geared directly to the rear axle. In the case of the White cars, Fig. 3, which were built in comparatively large quantities from 1904 to 1910, the engine was placed under the hood in front with a shaft running back to the rear axle. In the White car, a set of gears was also used in the

drive, by which the relation of engine to wheel speed could be reduced to one-half the usual amount, thus doubling the driving effort, or "torque". The White boiler was under the front seat. The new Doble, Fig. 4, uses the same general arrangement as the Stanley. In

Fig. 3. Side View of Doble Chassis
Courtesy of General Engineering Company, Detroit, Michigan

the Leyland steam truck, Fig. 5, and the National busses, both of England, the boilers are in front, the engines are under the floor boards, with a countershaft and final chain drive, as in Fig. 5, or a shaft drive direct to the rear axle.

Boiler and Engine Types. Almost equal variation is found in the types of boilers and engines. The difference between fire-tube,

Fig. 4. Side View of Doble Steam-Car Chassis
Courtesy of General Engineering Company, Detroit, Michigan

water-tube, and flash generators is taken up in the section devoted to boilers, while the engine types are taken up in their respective section.

Fig. 5. Leyland Steam Truck with Chain Drive to Rear Wheels
Courtesy of Leyland Motors Company, Ltd., England

Some of the cars use the water over several times by condensing the steam in coolers, or "condensers", placed at the front of the car. The

White and Lane did this, and it is now done by the Stanley, Doble, and most of the English steam cars and trucks. The Stanley, up to 1915, had no condensers, allowing the steam to escape into the air after it had passed through the feed-water heater.

Simplicity of Control. As a general rule, the steam cars do not employ a transmission for giving various forward-gear ratios and a reverse. The extra heavy loads, as in starting, are taken care of by lengthening the cut-off and by "simpling", terms which will be more fully explained later. Instead of running the engine always in one direction and using a gearset for reversing the car, as is done on gasoline automobiles, the engine is itself reversed by means of changing the timing of the valves through the aid of the valve gear, or linkage.

This change of the valve-timing is used only at starting, reversing, or under very heavy load conditions, all ordinary running being accomplished with the cut-off in one position. The control of the speed of the car, therefore, is accomplished under normal conditions by changing the amount of steam going to the engine. The steam is turned on or shut off by a hand-operated valve, known as the "throttle valve", and this valve is turned by a lever, or second small wheel, just above or below the steering wheel. Thus the actual driving of a steam car consists of steering and operating the throttle. There are, however, numerous gages, valves, etc., which have to be worked upon when firing up, and which have to be given occasional attention on the road; these will be considered in detail in the following pages.

Having treated in a general way the different types of steam cars and their parts, the theory underlying the behavior of steam will be touched upon before taking up the details of construction and the operation of the various units.

HEAT AND WORK

HEAT TRANSMISSION

All forms of energy, such as light, sound, electricity, and heat, are believed to be different forms of vibration either of the molecules of material substances or of the ether which is believed to pervade all space.

Energy is indestructible, but any form of energy may be converted into any other form. Steam engines are classed as heat

engines since they are employed to transform heat energy into mechanical work. Heat may be transmitted from one body to another in three ways, namely, by radiation and absorption, by conduction, and by convection.

Radiation and Absorption. Radiation is the transfer of heat from one body to another body not in contact with it. It takes place equally well in air or *in vacuo*. The rate of heat transferred depends partly on the distance separating the two bodies, and partly on the nature of their surfaces. In general, light-colored and polished metal surfaces radiate heat more slowly than rough and dark-colored surfaces. The laws governing absorption are the same as those governing radiation.

Conduction. Conduction is the transfer of heat through the substance of a body—solid or liquid—to other portions of the same body, or to another body in physical contact therewith. Metals are the best conductors of heat, but some metals, such as copper, are better conductors than others. Other solids, such as stone, wood, etc., rank after the metals. Liquids are very poor, and gases still poorer, conductors of heat. A vacuum is perfectly non-conducting, though radiation may still take place through it.

Convection. Convection is the term applied to the absorption of heat by moving liquids or gases in contact with heated surfaces. If a blast of air be directed on a piece of hot iron, the iron cools far more rapidly than it would in still air. The reason is that, as the air is a poor conductor, its molecules do not transmit heat readily from one to the next, but if each molecule on becoming heated is immediately replaced, heat is rapidly transferred. This property of air of taking up heat rapidly when blown over a hot surface is employed in gasoline automobiles to cool the so-called "radiators". In reality, the heat radiated cuts a small figure compared with that dispersed by convection.

What has just been said regarding air is equally true of other gases. It is also true of most liquids.

Relative Conductivity. Heat conducting qualities vary for different substances. Silver, copper, and aluminum conduct heat very rapidly, while asbestos is a poor heat conductor and is therefore used around the outside of automobile boilers.

Expansion. Another heat property which has to be con-

sidered in the selection of material for steam cars is that of expansion. Some metals expand much more than others for each degree of rise in temperature. Since brass and copper both expand under heat much more than iron they are used in preference to iron in the construction of expansion tubes, which are fully described later.

Temperature Measurement Scales. Temperature, which is the measure of the intensity of heat, is expressed by means of divisions called *degrees* on some thermometer scales. The two thermometers in most general use are the Fahrenheit and Centigrade; the former being the more common in America and England for both engineering and household use, while the latter is used exclusively on the Continent.

Freezing of water occurs at 32° F. (Fahrenheit) and boiling of water at 212° F. The scale between these two points is divided into 180 equal parts. On the Centigrade scale, the points of freezing and boiling occur, respectively, at 0° C. and 100° C., and there are, therefore, 100 equal divisions between the two points, Fig. 6. Thus it is seen that every 5 degrees Centigrade equal 9 degrees Fahrenheit.

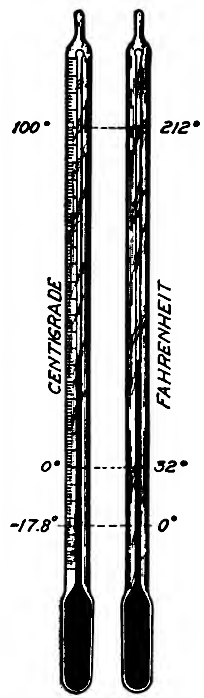

Fig. 6. Centigrade and Fahrenheit Thermometers, Showing Comparison

Conversion of Scales. To convert readings in one scale to readings in the other, the reading given is substituted in the following equation:

$$\frac{°F-32}{180}=\frac{°C.}{100}$$

Thus, if a temperature is given as $-5°$ C. it is equal to 23° F.; 23° C. equals 73.4° F. Conversion tables over large ranges are given in engineering handbooks, such as Kent.

Absolute Zero. In engineering calculations the absolute zero and the absolute scale are sometimes spoken of. This absolute zero, which will be mentioned again, is taken as $-270°$ on the Centigrade scale and $-460.6°$ on the Fahrenheit scale. Thus $-5°$ C. equals $+265°$ on the C.-absolute scale and $+483.6°$ on the F.-aboslute scale.

LAWS OF GASES

Almost all substances expand with rise of temperature. Solids expand least, and in some the expansion is imperceptible. Liquids expand about as much as solids, sometimes slightly more. Gases and vapors expand a great deal if free to do so.

Boyle's Law. Before considering the expansion of gases under changes in temperature, let us see how they act when the temperature is unchanged. A gas is perfectly elastic, that is, if not confined in any way it would expand indefinitely. The attraction of gravity is all that prevents the atmosphere surrounding the globe from dispersing into infinite space. When air is partly exhausted from a closed vessel, the remainder, no matter how small, expands so as to distribute itself equally throughout the vessel.

If a cubic foot of air at atmospheric pressure be compressed into one-half cubic foot without change in temperature, its pressure will be precisely twice what it was before. In speaking of gas pressures in this manner, it is customary to deal with absolute pressures, that is, pressures above a perfect vacuum. Thus atmospheric pressure at sea level is approximately 14.7 pounds per square inch, and a cubic foot of air reduced one-half in volume will have an absolute pressure of 29.4 pounds.

This relation of pressure and volume is expressed in "Boyle's Law", which states that, so long as the temperature is unchanged, the product of the pressure and volume of a given weight of gas is constant. That is

$$P\,V = C$$

This is the most important of all the laws of gases.

Curve Expressing Boyle's Law Relation. Fig. 7 expresses the relation between volume and pressure of a given weight of air starting at atmospheric pressure and compressed to a pressure of 500 pounds without change in temperature; also expanded to a pressure of one pound absolute. Horizontal distances represent volumes, the volume at atmospheric pressure being unity; and vertical distances represent absolute pressures. To find the pressure of the air for any volume greater or less than one, locate the given volume on the base line, then, from this point, read up to the curve and find the desired pressure by moving horizontally from the curve to the scale at the left.

Behavior of Gases with Changes of Temperature. As heat is a mode of motion, it follows that when all heat is withdrawn motion ceases, and the molecules, even of a gas, become fixed. From experiments and theoretical considerations the absolute zero, representing the absence of all heat, is believed to be −273° C., or approximately −460° F. In most theoretical studies of the behavior of gases, temperatures are reckoned from absolute zero instead of from the arbitrary zeroes of the conventional thermometer.

When a gas of given weight at an absolute temperature of 273 degrees—that is, 0° C. on the customary scale—is raised in temperature one degree without change in pressure, its volume is increased $\frac{1}{273}$. A second degree of added temperature increases its volume the same amount, and so on. In other words, for each degree Centigrade of added temperature its volume is increased $\frac{1}{273}$ of its volume at 273° A.

Volume

Fig. 7. Curve Showing Relation between Volume and Pressure of Air

If degrees Fahrenheit are taken instead of Centigrade, the expansion is $\frac{1}{491}$ of the volume at 32° F. for each degree of rise in temperature. Five degrees C. equal nine degrees F.

If the gas thus heated is so confined that it cannot expand, it will suffer an increase in pressure in the same proportion, that is, $\frac{1}{273}$ of its pressure at 0° C. for each degree Centigrade. If the gas, instead of being heated, is cooled, its shrinkage in the one case or its loss of pressure in the other will follow the same rule as above. Theoretically it follows that at −237° C.—absolute zero—the gas would have no volume at all. Of course that is impossible, but at ordinary temperatures the gases behave as if the assumption were true.

HEAT TRANSFORMATION

Specific Heat. The temperature of a body and the heat it contains are two different things. A gallon of water at 100° F. contains twice as much heat as half a gallon at the same temperature. That is to say, twice as much heat was imparted to it in raising it to that temperature.

Like quantities of different substances at the same temperature do not always contain the same quantity of heat. A pound of water contains more heat than a pound of oil or alcohol at the same temperature. It requires 7.7 times as much heat to raise a pound of water one degree in temperature as a pound of cast iron.

The quantity of heat required to change the temperature of a given weight of a substance one degree, compared with that required to change the temperature of the same weight of water a like amount, is called the "specific heat" of that substance.

Specific heat varies considerably for different substances, and for different temperatures and states of the same substance. Thus the specific heat of steam is much less than for water and varies slightly as the temperature and pressure of the steam is varied.

British Thermal Unit. The quantity of heat required to raise the temperature of one pound of water one degree F. is known as the "British thermal unit" (B.t.u.). Another unit is the "calorie", which is the quantity of heat required to raise the temperature of one kilogram (2.2046 lb.) of water one degree Centigrade. One calorie equals 3.968 B.t.u. The B.t.u. is the unit generally used in this country for engineering calculations. The latest investigations lead to slightly different and more complicated definitions of the B.t.u. from the one given above, but this is near enough for practical calculations.

Heat Value of Fuels. The number of heat units liberated by burning a pound of fuel varies for different fuels. The *heat value* for fuels is determined by experiment, and by calculation when the chemical composition is known. Due to the variation in the composition of commercial gasoline, different samples will give different results, but for most calculations the figure of 19,000 B.t.u. Kerosene has a slightly higher value.

Force. Force is defined as that which produces, or tends to produce, motion, and in practical work is usually expressed in units

of weight, for example, pounds, kilograms, or tons. A force may exist without any resulting motion, and therefore without work being done. For example, the weight of any object represents the force of gravity attraction between the earth and that body. The atmosphere exerts a pressure or force of approximately 14.7 pounds per square inch at sea level.

Work. Work is done when force is exerted by or on a moving body, and is measured by the product of the force into the distance through which it is exerted. A convenient unit of work is the "foot-pound", which is the work done in lifting a weight of one pound against the force of gravitation a vertical distance of one foot, or exerting a force of one pound in any direction through a distance of one foot.

Power. Power expresses the rate at which work is done. If a foot-pound of work is performed in a minute, the power is small. If it is done in a second, the power is 60 times as great. The customary unit of power is the horsepower, which is 33,000 foot-pounds per minute. Whether a force of 33,000 pounds be exerted through one foot of distance, or one pound be exerted through 33,000 feet in the same time, the power is the same.

Mechanical Equivalent of Heat. Heat may be converted into work or work into heat. Experiments have been made in which water was agitated in a closed vessel by means of paddles run by falling weights and the resulting rise in temperature of the water carefully determined. From these and other experiments, it has been ascertained that one British thermal unit is the equivalent of 778 foot-pounds of work. That is, a weight of one pound falling 778 feet, or 778 pounds falling one foot, develops sufficient energy to raise one pound of water one degree F. in temperature. A horsepower, therefore, equals 42.416 B.t.u. per minute. The combustion of one pound of either gasoline or kerosene liberates approximately 19,900 B.t.u., but the kerosene is heavier for equal bulk. One U. S. gallon of gasoline weighs about 5.6 pounds; of kerosene, about 6.25 pounds. The combustion of a gallon of kerosene per hour develops theoretically about 49 horsepower but the actual amount of energy obtained falls far short of this. Owing to heat losses in the boiler and exhaust, and to radiation, etc., only a small fraction of this energy can be converted into useful work.

THERMODYNAMICS OF STEAM

Latent Heat. If water be heated in an open vessel it will reach a temperature of approximately 212° F. (100° C.) and will then boil away without further rise in temperature. The added heat is absorbed in converting the water into steam.

It takes far more heat to convert water into steam than to raise its temperature. A pound of water heated to boiling from 32° F. absorbs only 180 B.t.u., but in boiling away at 212° F. it absorbs 966 B.t.u. additional. At atmospheric pressure the volume of the steam is 1645 times the volume of the water whence it came. This bulk of steam must displace an equal bulk of air, and part of the heat energy represented by the steam has been spent in pushing back the air to give it room. This will be made clearer from the sketch, Fig. 8, showing a long tube open at the top and containing a little water at the bottom. On top of the water is a piston, supposed to be air-tight and without weight or friction. If the water be boiled into steam, the piston will be pushed upward against the atmospheric pressure a distance equal to 1645 times the original depth of the water. The work in foot-pounds thus done will be 14.7 times the area of the piston in square inches times the distance in feet through which it has moved. Approximately 7.45 per cent of the heat imparted to the steam represents work done against the atmosphere; the remainder is spent in overcoming the mutual attraction of the molecules of water. The heat which has been absorbed by the change in state from water to steam without change in temperature is called the "latent heat of vaporization".

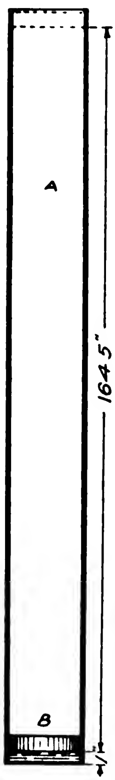

Fig. 8. Expansion of Water into Steam

If a vessel containing water at 212° F., which is the atmospheric boiling point, be put under the receiver of an air pump and the air partly exhausted, boiling will take place spontaneously without further addition of heat. At the same time the temperature of the water will decrease, because part of the heat contained in it has been absorbed by the conversion of water into vapor. If the air pump keeps on working, the water will boil continuously while its temperature steadily descends. If the

experiment be carried far enough, with the vessel so supported that it can absorb little or no heat from adjacent objects, and if the vapor given off be rapidly absorbed, for example, by placing a tray of quick-lime or sulphuric acid adjacent, the water may actually be frozen by its own evaporation.

This experiment shows that the boiling point of water—and this includes other liquids also—is not a fixed temperature but depends on the pressure. All volatile liquids when exposed to partial or complete vacuum give off vapor; on the contrary, this vapor when subjected to pressure partly re-condenses and a higher temperature is needed to produce boiling. Under an absolute pressure of 147 pounds or 10 "atmospheres", the boiling point is 356.6° F. At 500 pounds absolute pressure the boiling point is 467.4° F. (242° C.).

The "total" heat of steam at the boiling point corresponding to a given pressure is the sum of its latent heat of vaporization and the heat contained at the same temperature in the water from which the steam was formed. The total heat of steam increases slowly, but the latent heat diminishes nearly in proportion as the boiling point rises. The space occupied by a given weight of steam diminishes approximately in proportion to the increase in pressure. In this respect the steam resembles a perfect gas without change of temperature in accordance with Boyle's Law. Tables showing the pressures, temperatures, latent heat, etc., of steam are given in Kent and other handbooks.

The experiment just cited of producing spontaneous boiling in water by exhausting the air above it, may be duplicated with hot water at any temperature and pressure. For example, the boiling point of water under 100 pounds absolute pressure is 327.6° F. If, in a boiler containing water at that temperature and pressure, the pressure be reduced to 50 pounds by the withdrawal of steam, the water will boil spontaneously, absorbing its own heat in doing so, until it reaches a temperature of 280.9° F., which is the boiling point for 50 pounds absolute pressure.

Cause of Boiler Explosions. Owing to the property of giving off steam under reduction of pressure, every steam boiler constitutes a reservoir of energy which may be drawn upon to carry the engine through a temporary period of overload. In other words, the boiler will give out steam faster than the fire generates steam, the difference

being supplied from the heat stored in the water itself. This is an exceedingly useful feature of the ordinary steam boiler. At the same time, and for the same reason, it is a source of danger in case of rupture of the boiler shell. If a boiler explosion involved simply the release of the steam already formed it would not be so serious a matter; but when a seam starts to "go" the adjacent portions are unable to carry the abnormal strain put upon them, and the result is a rent of such proportions as to release almost instantly the entire contents of the boiler. The hot water thus suddenly liberated at high temperature bursts into steam until the whole mass drops to a temperature of 212 degrees, and this steam is many hundred times the volume of the water from which it came. It is to this fact that the violence of boiler explosions is due.

To take an extreme case, if a boiler bursts under 500 pounds pressure, approximately thirty-seven per cent of the water it contains will pass instantly into steam, and at atmospheric pressure the volume of the steam will be over 600 times the volume of the entire original liquid contents of the boiler.

Automobile boilers and steam generators are so designed as to minimize the danger of explosion, and only ordinary care is needed to insure entire safety.

Superheating. The foregoing paragraphs have dealt exclusively with steam at the boiling temperature due to its pressure. Such steam is called "saturated" steam. Steam will not suffer a reduction of temperature below this point; if heat be absorbed from it a portion will condense. On the other hand, steam isolated from the water whence it came may be raised in temperature indefinitely. It is then called "superheated" steam. The more it is superheated the more nearly does it act like a perfect gas.

Superheated steam is preferred for power purposes to saturated steam, for the reason that the latter condenses more or less, both in the pipes on its way to the engine and in the engine itself. Steam which condenses thus is a total loss, and it is more economical to add sufficient heat to it before it reaches the engine to replaces radiation losses, etc., without cooling the steam to the saturation point. To accomplish this in automobiles, the steam from the boiler is led through one or more pipes exposed to the maximum temperature of the fire. These pipes are called superheaters, or superheating pipes.

MECHANICAL ELEMENTS OF THE STEAM ENGINE

General Details of Steam Engine Parts. In Fig. 9 a plan view of a stationary steam engine is given, with the cylinder and valve chest shown in cross section, and with the various parts marked by letters. A view of a stationary engine is used because it is not so condensed as an automobile engine, and the parts are therefore easier to mark and pick out. The relations and names of parts are the same in an automobile engine.

Fig. 9. Plan View of Typical Stationary Engine

A, Cylinder. *B*, Outer cylinder head. *C*, Piston rod. *D*, Crosshead. *E*, Connecting rod. *F*, Crankpin. *G*, Crank. *H*, Crankshaft. *I*, Eccentric. *J*, Eccentric rod. *K*, Eccentric crosshead. *L*, Valve stem. *M*, Steam chest. *N*, Steam pipe connection. *PP*, Flywheels. *Q*, Crosshead guides. *R*, Valve stem guide. *S*, Engine frame. *T*, Stuffing box. *U*, Piston. *V*, Wristpin. *WW*, Steam ports. *X*, Slide valve. *Y*, Eccentric strap. *Z*, Clearance space between piston and cylinder head at end of stroke.

A is the cylinder to which steam is admitted through the passages, or ports, *W W*, which connect it with the steam chest *M*. The opening and closing of these ports is accomplished by the movement of the valve *X*. Because of its shape, the valve here shown is called a D-slide valve. Other types of valves are piston valves and poppet valves, names which explain themselves. The valve is attached to the valve stem *L* and is guided by the valve-stem guide *R*. Motion back and forth is given the valve by the eccentric *I*, which is a circular disk on the crankshaft, with its center offset from the center of crankshaft *H*.

Returning to the cylinder, *U* is the piston, which is driven back and forth by the steam. Connected to the piston is the piston rod *C*,

which passes through the gland, or stuffing box *T*. This gland is for the purpose of holding the packing which prevents the escape of steam around the piston rod. The end of the rod, or crosshead *D* slides back and forth in the crosshead guides *Q Q*. To the crosshead is attached the connecting rod *E*, by means of the wristpin *V*. In the lower end of the connecting rod is the crankpin *F*.

In steam automobile engines the flywheels *P P* are usually not needed and are consequently omitted. The rim of the gear wheel, when the engine is geared directly to the rear axle, has a slight flywheel action.

SLIDE VALVE

The leading mechanical elements of the steam engine have been briefly described. It remains now to show the precise manner in which the steam is used.

Elementary Slide Valve. Fig. 10 represents an elementary slide valve. In order to indicate the movements of the crankpin and the valve eccentric on one drawing, the crankshaft center is located at *A*. *B* represents the crankpin center with the piston *C* at the inner end of its stroke. The larger dotted circle is the crankpin circle, and the small circle is that in which the center *D* of the eccentric moves. With the crankpin traveling as the arrow shows, the valve is in mid-position when the piston starts to move, and the first effect of its movement is to uncover the steam port *E*, at the same time establishing com-

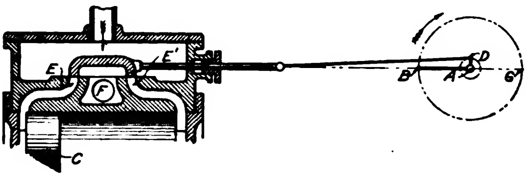

Fig. 10. Elementary Slide Valve—Valve in Mid-Position

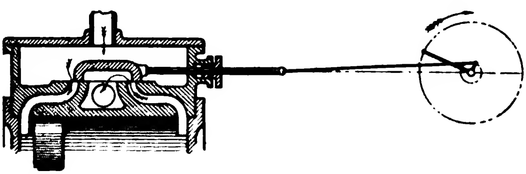

Fig. 11. Elementary Slide Valve—Inlet and Exhaust Ports Partly Uncovered

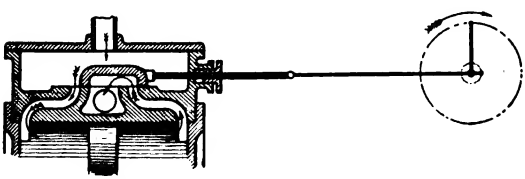

Fig. 12. Elementary Slide Valve—Inlet and Exhaust Ports Fully Opened—Piston in Mid-Position

munication between port E' and exhaust port F, Fig. 11. At half-piston stroke the ports are wide open and the valve starts to return, Fig. 12. When the crankpin reaches the outer dead center G the ports are again closed.

Use of Steam Cut-Off. A steam engine with valve arranged as above would take steam through the entire stroke, and would exhaust at boiler pressure. It would develop the maximum power of which it was capable at that pressure, but no use would have been made of

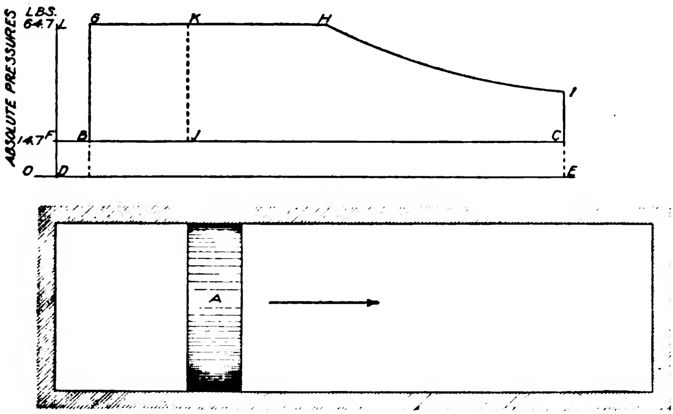

Fig. 13. Theoretical Indicator Diagram for One-Half Cut-Off

the expansion force of the steam. For this reason, all practical steam engines are made to admit steam only for the first portion of the stroke, that is, about one-half stroke or less, the remainder of the stroke being devoted to expansion. In Fig. 13, suppose A represents the position of a piston moving from left to right. The horizontal distance $B\ C$ represents the stroke, and vertical distances represent steam pressures. $D\ E$ is the line of zero pressure, and $F\ C$ that of atmospheric pressure. Suppose steam is admitted at 50 pounds gage pressure during the first half of the stroke from G to H; the steam port then closes and the steam expands with diminishing pressure along the curve $H\ I$. Since work is the product of force into distance traveled, it follows that for each fraction, such as $B\ J$ of the piston travel, the included area $B\ G\ K\ J$ will represent the work done during that portion of the stroke, and the area of the entire card $B\ G\ H\ I\ C$ will represent the work done during the whole stroke.

In the case under consideration, the area of the whole diagram is 84.4 per cent of that which would have been produced if the steam had entered during the entire stroke, yet only half as much steam is used.

Indicator Diagrams. A diagram such as Fig. 13 is called the "indicator diagram" or "indicator card", and is employed to study the internal action of the engine. The expansion curve of steam follows Boyle's Law with sufficient closeness for practical purposes. Fig. 14 is similar to Fig. 13 except that the steam is cut off at one-quarter stroke, point *H*.

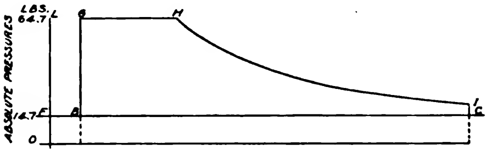

Fig. 14. Theoretical Indicator Diagram for One-Quarter Cut-Off

In the foregoing, no mention has been made of the contents of the steam passages between the slide valve and the cylinder, or of the clearance volume between the piston and the cylinder head when the crank is on dead center. These clearance spaces cannot wholly be avoided, but it is desirable to reduce them as much as possible. It is customary in indicator cards to represent the clearance space by an area to the left of the actual indicator card. This area is *F L G B* in Fig. 13 and Fig. 14. Its volume averages about 5 per cent of the volume swept by the piston. Owing to the necessity of taking the steam in the clearance space into account, the actual steam consumption in Fig. 14 is a trifle more than half that in Fig. 13.

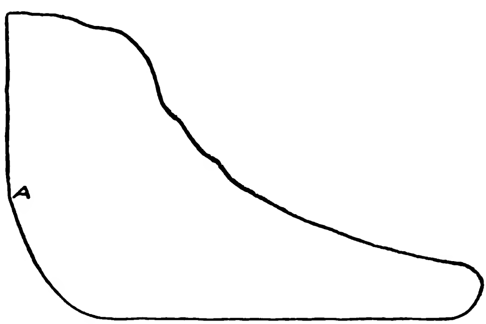

Fig. 15. Actual Indicator Card, Showing Compression

Effect of Compression on Indicator Card. The objectionable influence of the clearance may be neutralized by closing the exhaust port before the piston has finished its return stroke, thereby trapping the remaining steam at atmospheric pressure and compressing it to boiler pressure. If this is done, none of the entering steam is wasted

merely in filling the clearance space. Fig. 15 shows the effect of compression on an actual indicator card. It is not carried to boiler pressure, but only to point A.

Another reason for using compression is to cushion the reciprocating parts at the end of their stroke and prevent the shock which may otherwise occur on suddenly admitting live steam.

Effect of High Pressure and Early Cut-Off. As Fig. 14 shows, no great advantage is gained when working with steam at 50 pounds by cutting off earlier than one-third stroke. If higher pressure is used, however, the cut-off can be considerably shortened. Fig 16 is a theoretical indicator diagram for 200 pounds gage pressure (214.7 absolute). The clearance is 5 per cent of the piston displacement, and cut-off occurs at one-tenth stroke. The weight of steam per stroke is about the same as in Fig. 14, but the work done by the higher pressure is nearly two-thirds greater. This shows strikingly the economic advantage of using high pressure, provided the cut-off is shortened to correspond.

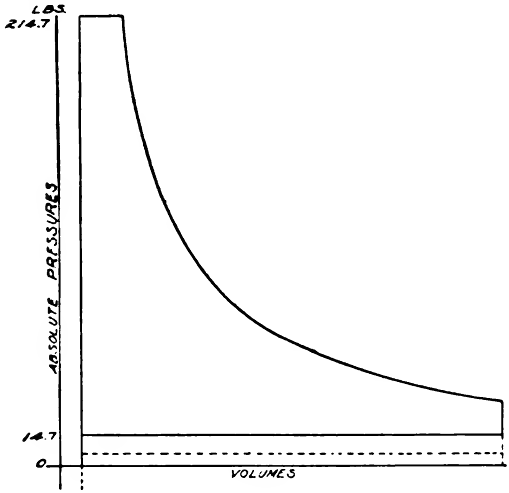

Fig. 16. Theoretical Indicator Card for One-Tenth Cut-Off

Effect of Adding Steam Lap. To produce a short cut-off, what is known as outside lap or steam lap is added to the edges of the slide valve A A, Fig. 17. To produce compression inside exhaust lap B B is also added. Figs. 18 and 19 show how the valve mechanism is affected by these changes. In Fig. 18 the piston is about to begin its stroke, but the valve is no longer in mid-position. Instead, the eccentric has had to be advanced through an angle, known as the "angle of advance", in order

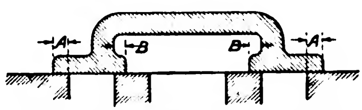

Fig. 17. Section of Slide Valve, Showing Steam and Exhaust Laps

to open the port as the piston starts to move. The necessary travel is also increased in order to accomplish the idle movement when all ports are closed. As the diagrams show, the valve reaches the end of its movement, returns, and closes the steam port while the piston is in the first quarter of its movement. It then continues to move, but with only the exhaust open.

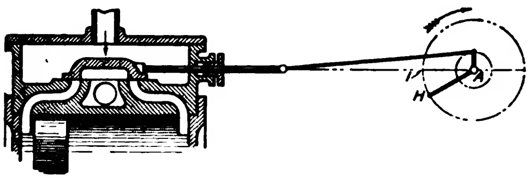

Fig. 18. Elementary Slide Valve, Showing Effect of Adding Laps

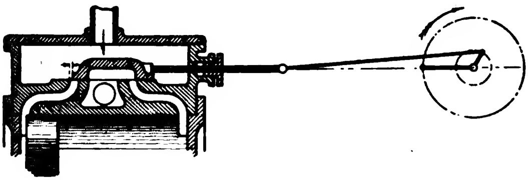

Fig. 19. Elementary Slide Valve, Showing Adjustment of Lead

It is customary, as Fig. 19 shows, to open the steam port a trifle before the piston begins its stroke in order to avoid wire drawing of the steam before the port goes fairly open. If this were not done, there would be an appreciable drop in pressure at the beginning of the stroke. The amount of this premature opening of the valve is called its "lead".

SUPERHEATED STEAM AND COMPOUND EXPANSION

Superheating to Avoid Cylinder Condensation. When steam expands its temperature drops by reason of expansion, causing the cylinder walls to assume an average temperature which slightly increases from contact with the hot steam and slightly diminishes at the end of every stroke. The hot entering steam condenses on the walls, and re-evaporates near the end of the stroke. This is very undesirable, and is avoided by superheating the steam sufficiently to compensate for the initial loss of heat to the walls. In addition, heat loss by radiation is minimized by lagging the cylinder walls and heads with asbestos, magnesia, or other non-conducting coverings.

When steam is used at pressures above 100 pounds, compound engines are preferable, although not always used.

Compound Engines. In a compound engine the work done by expansion is divided as nearly equal as practicable between two

cylinders, called respectively the high-pressure and the low-pressure cylinder. The high-pressure cylinder is the smaller in diameter, and it exhausts into the low-pressure cylinder instead of into the atmosphere. In the diagram, Fig. 20, showing the elements of a compound engine, the steam is being transferred from the high-pressure cylinder to the low-pressure cylinder. The steam expands by reason of the difference in the areas of the two pistons.

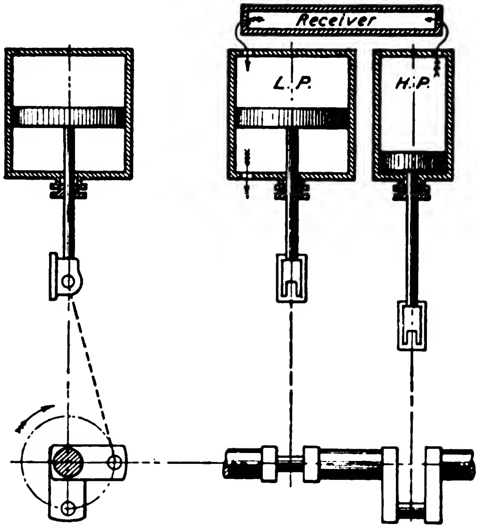

Fig. 20. Elements of a Compound Steam Engine

A compound engine may be considered as though the steam were expanded wholly in the low-pressure cylinder, and the indicator diagrams of the two cylinders may be combined to show the total work done, by shortening the horizontal distances of the high-pressure card in proportion to its smaller piston area.

Comparison of Indicator Diagrams for Stationary and Automobile Engines. Fig. 21 is a combined diagram from the high- and low-pressure cylinders of a stationary compound engine. Both cards are drawn to the same scale as regards stroke, but the low-pressure card reads from right to left. *F* is the point of admission to the high-pressure cylinder. The slight peak at *A* is due to the inertia of the in-rushing steam. At *B* the admission valve closes. At *C* the steam is released and goes into the receiver between the cylinders. *D E* is the

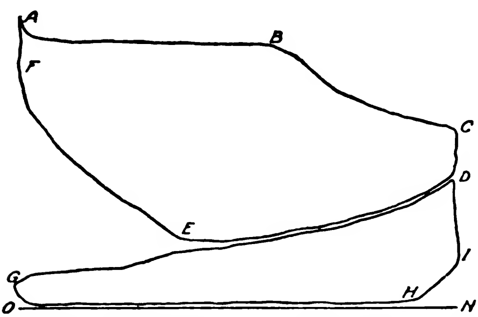

Fig. 21. Indicator Diagram of a Stationary Compound Steam Engine

exhaust line, and $E F$ the compression line. From D to E steam passes from the high- to the low-pressure cylinder, the difference between the two lines being due to frictional resistance of the passages. At G the exhaust valve opens. HI is the compression line of the low-pressure cylinder.

Use of Condensers. In the foregoing paragraphs steam is supposed to be exhausted at atmospheric pressure. In other words, the steam in the working end of the cylinder must overcome a back pressure of 14.7 pounds per square inch in the exhaust end. If the exhaust steam were discharged into a closed vessel and condensed, a vacuum would be formed containing only water vapor at a pressure

Fig. 22. Stanley Radiator

Fig. 23. Doble Radiator

proportionate to its temperature. This would mean the addition of 5, 10, or even 12 pounds to the height of the indicator card without having to increase the heat units put into the steam. To do this requires considerable apparatus—condenser, vacuum pump, etc., all of which it has been found inadvisable to install on an automobile.

Condensers on steam cars are not for the purpose of increasing the total expansion by dropping below atmospheric pressure, but to condense the water at atmospheric pressure so as to be able to use it again and avoid having to fill the water tank so often.

As shown in Figs. 22 and 23, both the Stanley and the Doble use condensers of the same general construction and appearance as

the radiators used on the ordinary gasoline car. The exhaust steam from the engine enters at the top of the radiator and is forced downward by the steam which is following. As it passes down the radiator, the air going through the spaces between the water passages cools it, until, by the time it reaches the bottom, it has been condensed into water.

VALVE GEARS

Throttling and Reversing. Steam engines are regulated partly by the cut-off and partly by throttling. As has been pointed out above, it is impracticable to use a cut-off so short as to expand the steam to, or below, exhaust pressure. Beyond this point reduction of power must be had by throttling the steam on its way to the engine. The shortening of the cut-off, and the complete throwing over of the valve timing to the other side of the dead center to reverse the engine, may be accomplished by shifting the angular position of the eccentric on the crankshaft or by the use of one of several valve gears or linkages.

Types of Gears. Up to the last few years the most common gear was the "Stephenson Link", developed by Robert Stephenson and Company, in 1842. In locomotive work the Stephenson gear has been largely displaced by the Walschaert gear. Practically all the earlier steam automobiles used the Stephenson, but later some changed to the "Joy Gear", which is one of a number of radial gears employing linkages without the use of eccentrics.

Stephenson Link. The Stephenson link is shown in Fig. 24. It consists of two eccentrics *A* on the crankshaft—one for the forward motion and the other for the reverse. The two eccentric rods are pinned to the link *B*, in which there is a curved slot. In the slot is carried the block *C*, which is a sliding fit and is pinned to the valve stem.

By means of the hanger rod *D* and the reverse lever arm *E*, the link is moved up and down, so that the slide is in different positions from the center of the slot. When the block is on one side of the link center it partakes of the motion of one of the eccentrics, and when on the other side of the motion of the other eccentric. Thus the valve timing is changed from the forward running position to the reverse by changing the position of the block in the curved slot.

It is a feature of the Stephenson link motion that by rocking the link toward (but not to) its mid-position the valve travel and cut-off are shortened, and this feature is utilized to improve economy. At the same time the lead is increased, that is, steam is admitted before the piston begins its new stroke. This is not a disadvantage

Fig. 24. Stephenson Link Motion Used on Stanley Steam Cars

at high speeds, as the fresh steam has a cushion effect on the reciprocating parts. At low speeds, however, the engine runs jerkily, and consequently the cut-off is shortened only at medium to high speeds.

Joy Gear. The Joy gear is a well known English development, which is used on a number of steam automobiles. Its operation may

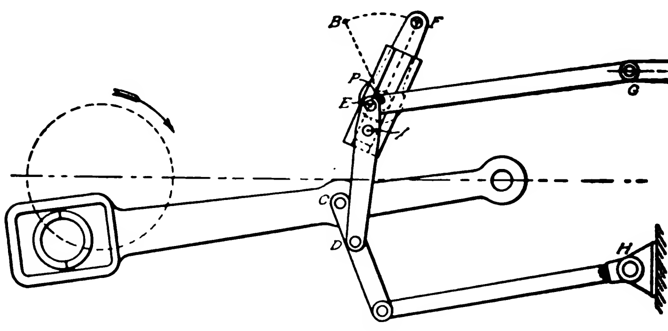

Fig. 25. Diagram of Joy Valve-Gear Mechanism

be understood by referring to Fig. 25. A link is pinned at one end to the engine at *H* and at the other end to a link, which in turn is pinned to the connecting rod at *C*. To this second link is pinned the link

D E, to the upper end of which is attached the rod *E G*, which moves the valve. At *A* on *D E* is pivoted the block *A*, which slides in the slotted guide, the guide being slightly concave on the side toward the valve. This guide is pinned to the engine frame at its center point *P*. In the position of the guide, as shown, the valve is in full gear for forward running, but if the guide is swung about the point *P*, by means of a connection at *F*, until it is in the position *B F*, the engine will then be in full reverse.

As with the Stephenson, the moving of the Joy toward the half-way point shortens the cut-off. This gear has an advantage over the Stephenson in that the lead is not increased and the distribution of steam to the two ends of the cylinder on short cut-off is more nearly equal. The Joy gear also gives a rapid opening and closing to the valve.

ENGINE TYPES AND DETAILS

Although makers have their individual preferences in engine types as regards the placing of the cylinders, compounding, and other features, the practice of using two cylinders has become almost universal.

Stanley. An example of the two-cylinder type is the Stanley engine, which, in the present models, is made in three sizes of the following bore and stroke: $3\frac{1}{4}$ by $4\frac{1}{4}$, 4 by 5, and $4\frac{1}{2}$ by $6\frac{1}{2}$ inches. This engine is geared directly to the rear axle by a spur gear mounted on the crankshaft, as shown in Fig. 26, and the frame rods are attached radially from the axle housing. The cylinder end is attached to the frame of the car. The rear-axle gear ratio in the small light runabout model is 30 to 56, and in the heavy delivery car is 40 to 80. With a gear ratio of 40 to 60 in one of the touring cars the engine turns over at 447 r.p.m. when the car is running 30 miles per hour.

Both cylinders take high-pressure steam at both ends, the engine being of the double-acting, simple type. The steam chest, Fig. 27, lies between the two cylinders, with the D-slide valves driven by the eccentrics lying next to the drive-shaft gear. In Fig. 26 is shown the Stephenson link by which the cut-off is hooked up and the reversing of the engine accomplished. This valve gear has been described in detail on page 23. The cross shaft, working the link, and the hook, for holding it in the normal position, are shown just to the left of *A*.

The hooking up is done by the left pedal, which can be released by a pedal beside it called the clutch pedal.

Roller and ball bearings are used extensively in the Stanley motor. The crosshead bears on a plain crosshead guide, and the connecting-rod and eccentric-strap bearings are of the ball type. The counterweights are also shown in Fig. 26.

Lubrication of the outside parts is effected by enclosing the gears, crankshaft, and other parts in a sheet-metal case, which is kept about half full of moderately thin mineral oil. The lubrication of the cylinder walls is accomplished by feeding the oil into the steam line, and the special superheated steam-cylinder oil recommended is given fully in a later section.

The Stanley power pumps for water, fuel, and oil, shown in Fig. 46, are driven from the rear axle.

Fig. 26. Stanley Two-Cylinder Steam Engine, Showing Link Motion and Balanced Shaft

Doble. The Doble engine, shown in full length section in Fig. 28, is made up of two cylinders of the same size. It is of the simple-expansion double-acting type, and the interesting feature is that the uni-flow principle is employed. The cylinder bore is 5 inches and the stroke is 4 inches.

On top of the cylinders are the valve chests. Each valve is made up in two pieces so that it may lift when the compression pressure exceeds the steam pressure, as sometimes happens in slow running. This construction allows the use of high compression, which is desired at the

Fig. 27. Cylinder Construction of Stanley Steam Engine, Showing Steam Chest in Center

higher speeds. The gear used to control the valve motion is a modification and simplification of the Joy gear, Fig. 25. In the Doble gear the connecting and anchor links are done away with, and a straight rocker guide is employed. In starting, the cut-off is five-eighths stroke, and this same position is used for heavy pulling. For ordinary running, one-fifth stroke cut-off is used, while for economy and high speed it is reduced to one-eighth stroke.

Fig. 28. Section of Doble Engine
Courtesy of General Engineering Company, Detroit, Michigan

By the uni-flow principle is meant that the steam moves in but one direction within the cylinder. It enters through the inlet passage at the extreme end of the cylinder, expands against the piston head, and passes out of the exhaust ports, which are uncovered by the piston a little before it reaches the end of the stroke. It is claimed for this system that the thermal conditions are so good that the use of superheated steam, with its attendant troubles, is unnecessary.

Aluminum is employed for the crankcase, with large cover plates, top and bottom, for easy access to the moving parts. The accessibility of the valve gear is very well

shown in Fig. 29. The case, which has its cover removed, contains all the moving parts of the engine with the exception of the valves and pistons; and, since the case and the axle tubes, which are bolted to it, are oil-tight, all these parts are kept in a bath of

Fig. 30. Piston and Crosshead Guide of Doble Engine

oil. This oil keeps comparatively cool and as there is no combustion, it does not deteriorate as in the gasoline car.

A special design of long cast-iron gland is used for the piston rod at the cylinder, and there is a stuffing box where the rod passes into the crankcase. The crosshead guide is part of a cylinder, as

shown in Fig. 30, giving a large bearing surface. Annular roller bearings are used for the big end of the connecting rod, for the crankshaft, and for the differential. Hardened steel, running in hardened steel bushings, is used for all the other bearings.

Being geared at practically a 1 to 1 ratio to the axle shafts, the engine always runs at comparatively slow speed. A 47-tooth pinion is carried on the engine crankshaft and to this is fastened the counterbalance. This gear meshes with one of 49 teeth on the differential spider. The differential is of the three-pinion bevel-gear type. Meshing with the axle gear is an idler, and then a gear on the electric generator, which furnishes current for the combustion system and the lights.

Fig. 31. Top View of National Power Plant for London Steam Omnibuses
Courtesy of Society of Automobile Engineers, New York City

Fig. 32. Separate Engine and Dynamo for Lighting National Busses
Courtesy of Society of Automobile Engineers, New York City

National. In the National steam omnibuses of London, England, the engines are placed under the floor boards, Fig. 31, and,

unlike any of the American engines, the two cylinders lie across the chassis. The drive is taken by a shaft to worm gearing at the rear axle. These engines have a Joy gear, and the pumps for the water and kerosene are driven from a cross shaft, which in turn is driven by a worm gear off the extension of the crankshaft, as is shown in the illustration. An interesting feature of the National chassis is the use of an entirely separate steam engine for driving the electric-lighting generator, which supplies the large number of lights used inside the busses. This auxiliary engine is shown in Fig. 32.

From what has been said it must not be supposed that all automobile steam engines use two-cylinder engines with either D or piston valves. The Pearson-Cox steam truck of England has a three-cylinder vertical engine with poppet valves in chambers at each side of the cylinders, and the whole engine looks very much like a vertical poppet-valve gasoline motor.

A number of very heavy English trucks, or "lorries" as they call them, are driven by steam, and are very popular in England. These carry from 3 to 10 tons, and the boilers and parts of some of them are very large.

FUELS AND BURNERS

Gasoline and Kerosene as Fuels. Energy for driving steam engines is derived, of course, from the fuel burning and forming steam from the water, the steam in turn doing mechanical work by its expansion in the engine. In an automobile it is of prime importance that the fuel be as easily handled, carried, and purchased as possible. Of the commercial fuels, gasoline and kerosene come the nearest to these ideals and are, therefore, the most popular. Kerosene is less expensive than gasoline, but does not vaporize at as low a temperature while, as a rule burners are specially designed for kerosene, many modern burners will handle either of these fuels or a mixture of them.

To burn either of these fuels the vapor must be mixed with air, which supplies the necessary oxygen for combustion. Either of these vapors, if mixed with the right amount of air, is highly inflammable and explosive, and therefore, care must be taken in storing and in filling the fuel tank, not to have open lights about—not even lighted cigars.

Burner Principles. *Bunsen Burner.* The purpose of the burner is first to vaporize the liquid fuel by heating it and then to mix it with enough air to produce the hottest possible flame under the boiler. In principle the burner is the same as the ordinary Bunsen burner, Fig. 33, in which the gas passes under moderate pressure through the small opening *b*. In going up the tube *a* it draws in a certain amount of air through the openings *o*, the fuel gas and air becoming well mixed in the tube before reaching the flame. In case either too much or too little air is mixed with the gas, the flame will run back through the tube *a*, and will burn at *o*. This is called "popping back", and not only takes away the effect of the flame but will ruin the burner if allowed to continue in operation in this way.

Modifications for Automobile Work. In automobile work the burner is somewhat modified in order to act over a large area and to give a flame of more intense heat. For the purpose of feeding more gas, and to mix it more quickly with the air, the fuel is fed under considerable pressure.

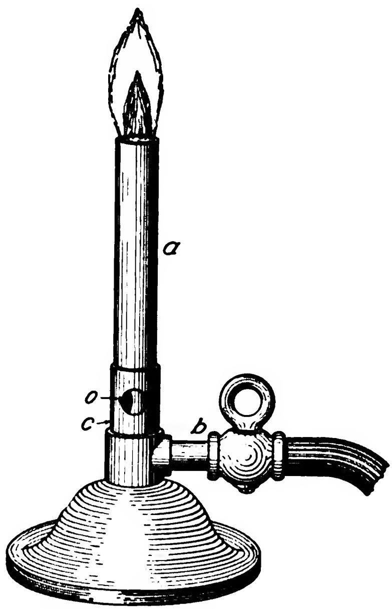

Fig. 33. Typical Bunsen Burner

The correct mixture of air and fuel gas gives a blue flame, just slightly tinged with orange at the top, and burning rather close to the burner. If too much air is given the mixture, the flame will start a considerable distance above the burner and will be very blue. The excess air tends to cool the flame. Too little air is equally bad, for the combustion will then be incomplete and, since gasoline and kerosene are hydrocarbons, soot will be deposited on the surfaces above the flame. Such a flame is indicated by a yellow color. As in the ordinary Bunsen burner, poor mixtures are apt to pop back. When this happens the operator must turn off the burner and relight it. The popping back is indicated by a roaring sound.

Pilot Light. As the demand for steam is not constant in an automobile, it is desirable to have the main burner come on and off automatically. In order to light the main burner whenever it may come on, a small light is kept burning continuously while the car is in use, whether running or standing still. It is even the practice of some owners to keep this pilot light, as it is called, lighted over night. Besides relighting the main burner when the car is running, the pilot is lighted first when firing up a cold boiler. The burning of the pilot serves to heat the vaporizer of the main burner as well as to light the main fire. The handling of the pilot in firing up will be taken up later.

Due to its easier vaporization, gasoline is always used for the pilot-light fuel even when kerosene is used for the main burner. It is also quite general to have the two fuel systems separate, although both may be using gasoline. In starting up a cold system the pilot vaporizer must be heated by some outside means. This is done in several ways: one is to use a separate gasoline torch; another is to use an acetylene torch instead of a gasoline torch; and a third method is to light a little pool of gasoline below the vaporizer, similar to the method used in many gasoline cook stoves and plumbers' torches.

Fig. 34. Stanley Burner, Showing Vaporizer and Mixing Tubes
Courtesy of Stanley Motor Carriage Company, Newton, Massachusetts

Types of Burners. Different makers, of course use somewhat different constructions for their burners, but in all cases the fuel gas is vaporized by heat and mixed in a burner of the Bunsen type. As a fair example of all the burners, that of the Stanley will be described in detail, while short descriptions will also be given of other makes.

Stanley. Either gasoline, kerosene, or a mixture of the two can be burned in the Stanley main burner. The burner, Fig. 34, consists of a corrugated casting with a large number of slots cut across the peaks of each parallel corrugation. Vaporization of the fuel takes

place in the two coiled tubes *A A* which lie directly over the fire. From the vaporizing tubes the gas flows at high velocity through the nozzles *B B* into the mixing tubes *C C* drawing with it the air necessary for good combustion. The mixing tubes lead under the burner, and combustible gas issues through the fine slots, where it burns with an intensely hot blue flame tipped with orange. No air currents are present to blow or cool the flame, for the burner casting excludes all air except that drawn in and mixed with the gas through the tubes *C C*. To adjust the amount of air to give the correct color to the flame, bend the nozzles closer to the opening of the mixing tube for less air, and *vice versa.*

Between the two main-burner vaporizer tubes is located the pilot light, which is a small independent casting. The pilot burns gasoline, supplied from a separate tank, irrespective of whether the main burner uses gasoline or kerosene. Due to the position of the pilot, it keeps the main-burner vaporizer warm when the main burner is shut off by either the automatic or hand valve controlling it. When the main burner is turned on, the pilot flame ignites the gas. Since the pilot is independent of the main-burner valves, it remains lighted until turned off by its own hand-operated valve. The heat from the pilot is sufficient to hold steam in the boiler for several hours after the car is stopped and the main burner shut off.

In starting up the pilot of the Stanley when cold, an acetylene torch is played on the pilot vaporizer to vaporize the first gasoline, after which the heat from the pilot light itself keeps the pilot vaporizer warm. The acetylene is carried in a "Prest-O-Lite" tank and turned on by a valve at the tank. The torch lights by simply applying a match, and should be played on the pilot vaporizer until it is sizzling hot, which takes between 15 and 30 seconds. The torch is then moved so that the flame enters the peek-hole, lighting the pilot, after which the torch is played upon the upper part of the vaporizer for 15 to 30 seconds, until the main burner nozzles are sizzling hot.

After closing the acetylene-tank valve the main-burner valve is opened and closed quickly several times until the gas from the main nozzles is dry. It is then left open, being lighted by the pilot flame. The pilot nozzle is provided with a wire which is filed off on one side to allow the passage of the gas. If the pilot light does not seem to burn strongly, it can be cleaned while burning by turning the outside

screw back and forth with a screwdriver. If this does not suffice, the wire should be taken out and cleaned; it is good practice to do this every day before firing up. The color of the flame can be adjusted by bending the nozzle tube to bring the nozzle in or out from the mixing tube, the same as is done in adjusting the main burner.

In the older models of Stanley cars, which used only gasoline as the main-burner fuel, the pilot fuel system was a branch of the main system, and the pilot vaporizer was heated by a gasoline torch.

Fig. 35. Section through Combustion Chamber and Boiler of Doble Car
Courtesy of General Engineering Company, Detroit, Michigan

Doble. Very radical departures from the long-established Bunsen type of burner have been made in the combustion system on the new Doble car. The fuel is ignited by electricity and there is no pilot light. Kerosene is used for both starting and running and is fed from the main fuel tank to a float chamber by an air pressure of three pounds per square inch. From the float chamber, which is of the standard gasoline-carbureter type, the fuel passes through a spray nozzle, which is located in the throat of a Venturi tube leading to the combustion chamber.

Air for the support of the combustion of the fuel is drawn through the radiator by means of a multiple-vane fan driven by a small electric motor. It passes the jet with sufficient velocity to draw out the fuel and atomize it. Owing to the enlarging of the passage directly beyond the throat, the velocity is decreased in order to give time for the complete combustion of the gas by the electric spark, which takes place at this point.

The combustion chamber, Fig. 35, is completely closed and lined with a highly refractory material. As soon as the combustion has been started, the electric spark is automatically shut off, and the burning of the gas is continuous until it is stopped by the action of the automatic steam control, as described later. The lining of the chamber not only has the property of resisting high heats, but it holds and gives back the heat so as to assist in completely burning the gases. The combustion chamber is also well illustrated in Fig. 41, page 40.

Fig. 36. Ofeldt Blue Flame Kerosene Burner
Courtesy of F. W. Ofeldt and Sons, Nyack-on-the-Hudson, New York

Ofeldt. The Ofeldt burner, Fig. 36, is designed especially for the use of kerosene as a fuel. Forming the foundation of the burner is a galvanized iron pan, lined around the sides with millboard asbestos. In the bottom of the pan are drilled rows of small holes. Since these holes are in straight lines under the burner pieces, and of equal size, they admit even amounts of air throughout the lengths of the burner pieces.

Fig. 37. Kerosene Burner, Used on National Busses with Starter
Courtesy of Society of Automobile Engineers, New York City

Cast iron is used for the burner pieces, which radiate from a

central gas-distributing chamber, into which they are screwed. The gas flows through fine slots cut in the burner pieces. Surrounding the mixing tube is the main vaporizer *A*, which passes through the outside of the pan, ending in the nozzle *B* at the opening of the mixing tube. The mixing tube is a part of the central gas-distributing chamber.

Attached below the burner pan is the pilot *D*, where its flame heats both the main and the pilot vaporizers and the mixing tube. By means of a hand valve the pilot flame can be adjusted to keep up steam when the main burner is out, or it can be turned down so as to keep only the main vaporizer warm.

A comparatively low pressure is used on the Ofeldt system, the fuel being kept under about 60 pounds per square inch.

National. Kerosene is used as the fuel in the National busses. These burners are quite different in appearance from those described above, as is shown in Fig. 37.

Fig. 38. Stanley Fire-Tube Boiler

AUTOMOBILE BOILERS

Classification. In stationary steam-power plants there are two distinct classes of boilers, the fire-tube and the water-tube. These two types are also used in automobile work, together with a third type, the flash boiler, which is a development of the water-tube type.

Fire-Tube Boilers. In principle the fire-tube boiler is like a big tea-kettle filled with vertical tubes, which run from the bottom to the top for the purpose of carrying up the flame and hot gases. This construction gives a very large surface on one side of which are water and steam and on the other flame and hot gases.

Stanley. One of the simplest of the fire-tube boilers is the Stanley, Fig. 38. This is made up of a pressed-steel shell, which includes the lower head, the upper head being a separate piece.

Between these two heads run a large number of tubes of $\frac{33}{64}$ inch outside diameter, which are expanded into the heads by a taper expanding tool. Stanley boilers are made in three sizes, 20, 23, and 26 inches in diameter and 14 and 16 inches in height, respectively. The number of tubes is 550, 751, and 999, giving 77, 104, and 158 square feet of heating surfaces. To keep down the radiation losses, the boiler shell is lagged with asbestos, and the strength of the shell is greatly increased by winding it with steel piano wire.

To keep a reserve of steam, and to have the steam free from particles of water, the boiler is kept only about two-thirds full of water, the upper space being filled with steam. To further insure dry steam at the engine the steam is led by a pipe from the top of the boiler down to a superheating coil directly over the burner.

Fusible Plug. As a warning against too low water the side of the boiler is provided with a fusible plug, held in a fusible-plug tube which, in turn, screws into a steel fitting. The elbows on this fitting are made on a taper and are driven into two short tubes in the boiler. As long as the water level is above these tubes the circulation prevents the plug from melting. If the water gets below the plug and about 3 inches from the bottom of the boiler, the plug will melt and the noise of the escaping steam will warn the operator of the danger—not danger of an explosion of the boiler, but danger of doing the boiler damage by heating it without water. There are other means by which the operator may know that the water is getting low before it gets low enough to blow out the plug, and these will be taken up in detail later, together with the causes of unexpected low water and other points.

The fusible plug may melt out, not only from low water but also because of dirt or something retarding the circulation of water around the tubes or fittings. The blowing off of the steam will usually remove the obstruction. If the escaping steam is dry, it is a sign that the melting has been caused by low water, but if it is wet the trouble is due to faulty circulation. It is good practice to replace the fusible plug once every two or three weeks, doing this when the boiler is cold.

Since the addition of the condenser to the Stanley in 1915, these boilers have been made without the fusible plugs. Among other improvements in these boilers is the brazing, or welding, of the tubes in the lower heads. This is to prevent any trouble from oil, which

might be carried over into the condensing system. Before the boilers are turned out from the factory, they are tested by a water pressure of from 1500 to 1800 pounds per square inch.

Water-Tube Boilers. Water-tube boilers also are made up of tubes, but in this case the tubes carry the water and steam *inside* and the fire and hot gases pass over the tubes. The metal hood over this type of boiler carries no pressure, but merely serves to keep in and direct the hot gases. In stationary practice the tubes are often straight or only slightly bent, but to economize space the automobile boiler has the tubes coiled to give the most surface to the fire in the least possible space.

Ofeldt. The Ofeldt safety water-tube boiler, Fig. 39, is built about a central standpipe of 5 inches or more in diameter, with a bottom of ½-inch metal welded in. Threaded into the upper end of the standpipe is a steel cap with three arms, to the ends of which the sheet-metal hood, or cover, is fastened.

The object of the standpipe is to hold a reserve of water at the bottom and of steam at the top, and to distribute the water to the coils. In the coils and standpipe the reserve of water varies from 3 gallons in the small sizes to 8 gallons in the 24-inch size.

Fig. 39. Ofeldt Safety Water-Tube Boiler

Water is fed to the bottom of the standpipe, from where it flows into the coils. As it passes up the coils it turns into steam. A pipe from the center of the standpipe carries the steam down to the superheater, which lies under the boiler directly over the burner, as shown in Fig. 39. From the superheater the steam is carried by the second straight pipe back to the top of the boiler and then to the engine.

These boilers are supposed to supply steam at 250 pounds pressure but are tested up to 1000 pounds per square inch.

Doble. Almost as great a departure from ordinary practice has been made in the Doble boiler as in the combustion system previously described. The generator is of the water-tube type, with the tubes

arranged in rows, which are really separate sections, Fig. 40. There are 28 of these sections in the generator part of the boiler. The tubes are made from seamless drawn-steel tubing of about $\frac{1}{2}$-inch diameter and are swaged down to a diameter of about $\frac{3}{8}$ inch at the ends. These ends are welded into the top and bottom headers, thus making each section a continuous piece of steel.

Besides the 28 sections of tubes in the generator portion, there are 8 more sections in the economizer or feed-water heater. The

Fig. 40. One Section of Doble Boiler
Courtesy of General Engineering Company, Detroit, Michigan

arrangement of all these sections is clearly shown in Fig. 41, the view being cut across each of the 36 sections, similar to Fig. 40. The picture does not show all the details but has been arranged to give an idea of the general layout and the direction of flow of the hot gases and of the water and steam. The boiler sections are completely covered over, except at the bottom, by a $\frac{3}{4}$-inch wall of heat-resisting and insulating Kieselguhr material. Over this is a planished iron jacket.

All of the sections are connected together by headers, which run along the sides of the boiler. One of the features of the construction is that if anything should go wrong with a section of tubes, it can be

very easily cut out of operation by means of the side headers, until such time as it is convenient to replace the section.

In Fig. 41, the direction of flow of the hot gases of combustion is shown by the heavy arrows, while the flow of the water and steam is indicated by the small arrows. From the combustion chamber at the bottom of the boiler, the gases pass upward and then over the top of the fire wall between the generator proper and the economizer. Here they turn and pass downward in order to escape through the

Fig. 41. Section through Doble Boiler, Showing Combustion Below and Economizer Section at Right

exhaust at the bottom. It should be noted that the power-driven feed pump forces the water in an upward direction in the economizer tubes, exactly opposite to that of the gas flow outside of the tubes.

From the top headers of the economizer sections, the water overflows through a manifold to the lower headers of the generator sections. An automatic valve controls the feed water, so that the water in the boiler, under normal conditions, stands about half-way to the top. On the road, the usual pressure is around 600 pounds per square inch, which is maintained by an automatic valve controlling

the fuel supply. Each section of the boiler is tested to a water pressure of 5000 pounds per square inch. The actual bursting pressure is said to be over 8000 pounds. As a precaution against any danger, however, a safety valve is attached to the boiler.

Flash Boilers. Flash boilers differ from the fire- or water-tube types, both of which have a reserve of steam, in that the steam is generated only in the quantity demanded each moment by the engine. These boilers consist of a continuous metal tube in one or more coils lying over the burner. As the water from the reservoir passes along the tube it gets hotter and hotter until at some point in the tube it bursts into steam. During the rest of its travel the steam is superheated.

As practically no steam is kept in reserve, the capacity of the boiler and burner must be great enough to supply at once the maximum demand for hill climbing. The relations of water and fire must be nicely balanced at all times to prevent too much superheat on one hand and wet steam on the other.

Safety against a dangerous explosion is the leading argument for the flash type of boiler. Since there is no reserve of steam or hot water under pressure, there is no large amount of energy to be liberated in case of a rupture of any part of the boiler.

Serpollet System. In the early days of steam automobiles a Frenchman named Serpollet reduced the amount of water in a boiler to an extremely small amount. To give the maximum of heating-surface area together with a minimum of cross-sectional area, the tubes were made a U-section instead of circular; this type, however, was abandoned later.

With the Serpollet system the fuel and water were fed simultaneously, one lever varying the strokes of both pumps. To avoid trouble from extreme superheat, single-acting pistons and poppet valves were employed. The valve cut-off was variable and worked in conjunction with the fuel and water supplies. Since there was no reserve of energy to the system, it took a great deal of skill to handle it smoothly, especially in hilly country.

White. A great improvement over the Serpollet system was the flash generator of the White Company. Although the White steam cars were discontinued in 1911, they were the leading example of the flash system in this country.

In the White generator there was a sufficient supply of water to serve as a reserve in cases of sudden demand. Referring to Fig. 42, it will be noted that the boiler was made up of several rows of tubes, each coiled in a horizontal plane, and each connected to the row below by a tube which first passes to the top of the boiler. Unlike the ordinary fire-tube or water-tube boilers, the water entered the White boiler at the top, through the pipe *128*. The upper coil was in the coolest portion of the gases from the burner. After passing through the top coil, the water flowed through the tube at the end of the coil, being carried up and over the top of the boiler and then down to the second coil, and so on down from coil to coil. Being nearer the burner, each coil was hotter than the one above, and,

Fig. 42. Generator, Burner, and Fuel Connections Formerly Used on White Steam Cars

since the vertical pipes at the ends of the coils kept the hot water from circulating back to the coil above, there was some point in the lower coils where the water burst into steam. The steam became superheated during the remainder of its travel through the coils and left the boiler by the pipe *129*.

These principles of construction were held to in all the White steam cars from 1904 to 1911 inclusive. Because of the strength of the small-diameter tubes and the small amounts of steam and water

in the boiler at any one time, it was possible to carry a working pressure in these generators of 600 pounds per square inch.

Special Types. *Lane.* The Lane boiler, Fig. 43, was a combination of the fire-tube and flash systems. The main part of the boiler was of the fire-tube type, with very large tubes. Above this were several coils of brass tubing, the water entering the top and getting hotter as it passed down the tubes until it was partly converted into steam by the time it passed into the main part. The water was here separated from the steam, falling to the bottom of the boiler, while the steam was superheated by coming in contact with the hot upper portion of the fire tubes.

Fig. 43. Lane Boiler

National. For the National London busses a water-tube boiler is used, and these stand a great deal of abuse, often being run dry by the carelessness of the drivers. As is shown in Fig. 44, these boilers are

Fig. 44. Water-Tube Boiler Used on National London Busses
Courtesy of Society of Automobile Engineers, New York City

built around a central steel drum, which is pressed from a single piece of metal.

BOILER ACCESSORIES AND REGULATION

Besides the main units of burner, boiler, and engine on the steam automobile, there have to be many other small units, most of them automatic in their operation, for the control of the fire, water feed, and engine to meet the conditions of the wide variations in road and driving conditions. These are the power pumps, the hand pumps, valves, feed-water heater, condensers, and others.

Check Valves. In the lines where it is desired to have the fuel, water, or steam pass in but one direction there are placed valves which allow only this one-way passage and are known as check valves. There are several types, including poppet, hinged, and ball checks. The latter, Fig. 45, is very largely used and consists of a ball which rests on a seat forming a ground, fluid-tight joint. When the fluid is passing in the desired direction it lifts the ball off the seat. The body of the valve is so made that it keeps the ball from being carried on down the line with the fluid. As soon as the direction of flow or pressure changes to the opposite direction the ball drops onto its seat, closing the valve against this opposite flow.

Fig. 45. Crane Ball Check Valve

Check valves are used in many places in the fuel, water, and steam lines, as is indicated by the diagrams further along. For instance, there are check valves on the inlet and outlet sides of the water pumps. When the piston is on the suction stroke, the inlet check is open while the outlet check is closed, keeping the water already pumped from being drawn back. As soon as the piston starts on the delivery stroke the inlet check closes and the outlet valve opens. This action applies to all the types of check valves.

If dirt lodges on the seats of a check it will leak and, if the dirt cannot be forced off by vigorous action through the valve, the valve must be opened up and the seat cleaned and possibly ground. In most check valves this can be done without removing the whole valve from the line.

Fuel System. Considerable fuel-carrying capacity is always provided in automobiles, and for this reason there should always be enough in the car for more than one run. Before starting out it is

always well to see that there is plenty of fuel in the main and pilot supply tanks. Not only is running out of fuel on the road very inconvenient, but the running-dry of the tanks may air-lock the pumps and cause a loss of considerable extra time in getting the

Fig. 46. Power Pumps of Stanley Engine

system back into smooth action. The above applies equally well to the water supply.

As mentioned in the section on burners, the fuel is fed under pressure. In some cases the pressure is carried on the main tank, while in other cases it is carried by air or spring pressure on small auxiliary tanks. The power and hand pumps on steam cars are of the plunger type.

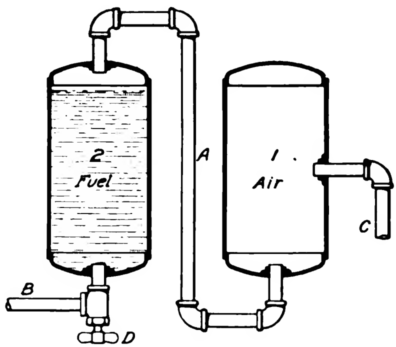

Fig. 47. Fuel Pressure Tanks on Stanley Cars

Due to the interrelations between the demands for steam, water, and fuel and the automatic devices, one controlled by the other, it is difficult to deal separately with the various units. For this reason one complete fuel, water, and steam system will be discussed and then descriptions of other makers' units and methods of operation will be taken up. The Stanley system will be used to show the relation and operation of the various units.

Stanley Fuel, Water, and Steam Systems. *Fuel System.* On the Stanley cars the main fuel tank is carried under atmospheric pressure and the fuel is drawn from the tank by the power-driven pump, Fig. 46. In series with the power fuel pump is a hand pump for use

when the engine is not running or if the power pump should be out of order. The *small pressure tanks* on the Stanley are shown in Fig. 47. The fuel does not flow through the left tank, marked *2*, but merely rises and falls in it, the tank acting as a pressure equalizer between the strokes of the power pump, similar to the standpipe in many city waterworks systems. Tank number *1*, on the right, is filled with compressed air, which is supplied by the power-driven air pump or by the hand air pump. A pressure gage on the dashboard shows the operator what the pressure is on the tanks. From the auxiliary tanks the fuel passes to the vaporizer.

Since the fuel power pump has a capacity greater than that usually demanded by the burner an *automatic by-pass valve*, called the fuel automatic relief, Fig. 48, is placed in the line. When the fuel from the pump is at a higher pressure than is being carried on the pressure tanks, the needle valve of this fuel automatic relief is raised and part of the fuel is returned to the main tank, as shown in the layout of the fuel system, Fig. 49.

Fig. 49. Stanley Fuel System
Courtesy of Stanley Motor Carriage Company, Newton, Massachusetts

Should this needle valve fail to seat properly, it is probably due

to dirt between the needle and the seat. This can often be removed by taking the tension off the spring by unscrewing the adjusting nut and then pumping fuel with the hand pump. If this does not cure the trouble the whole valve should be taken apart and cleaned and, if necessary, the needle ground into the seat.

Beyond the pressure tanks there is a *fuel filter* which should be watched for leaks and cleaned every once in a while. Near the tanks is also a pressure-retaining valve, which may be closed by hand when the car is left standing, the purpose being to keep the pressure on the tanks, as it might otherwise be lost, due to slow leaks in the lines, and thereby necessitate the pumping-up of pressure by hand.

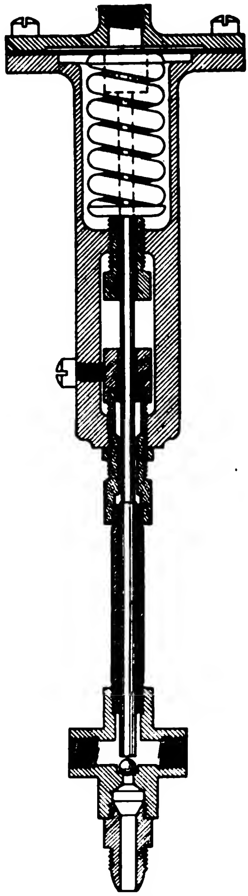

Fig. 50. Stanley Steam Automatic Valve

Actual fuel supply to the vaporizer, and hence to the burner, is governed by the steam automatic regulator, or "diaphragm regulator", as it is sometimes called, Fig. 50. This regulator governs the relation between the steam pressure and the fuel supply to the burner. It consists of a metal diaphragm, clamped between the cap and the body. When the steam pressure rises above the predetermined amount, the pressure against the diaphragm causes it to bulge and thus move the rod attached to it so as to keep the ball valve from leaving its seat, thereby shutting off the fuel to the boiler.

The strength of the spring determines at what steam pressure the fuel is shut off. To regulate the strength of the spring the adjusting screw is moved in or out. The valve stem is provided with a stuffing box which can be tightened up to stop leaks through the gland. The screw locks the gland in place after the adjustment is made. Care must be taken not to get the gland too tight.

Upon the older Stanley models, in which gasoline was used for the fuel of the main burner as well as for the pilot light, the line for

the latter was a branch of the main fuel line. In the newer models, the pilot system is entirely separate, so that kerosene may be used for the main burner. The pressure on the separate gasoline tank is pumped up by a hand pump and should be kept at from 20 to 30 pounds per square inch. In leaving the pilot burning over night the pressure will not fall over 5 to 10 pounds.

Water and Steam System. From the main water tank the water is drawn by two opposite *power-driven pumps*, Fig. 46, and follows the course shown in Fig. 51. A *hand pump* is also provided for use

Fig. 51. Diagram of Stanley Water System
Courtesy of Stanley Motor Carriage Company, Newton, Massachusetts

when the car is standing still or in case of a failure of the power pumps. Beyond the pumps are by-pass valves, the opening of which allows the water to return to the supply tank. The rear by-pass is operated by the usual type of handle, while the one in front is controlled by a lever on the steering post. The handling of these by-pass valves will be taken up in relation to the general operation of the car.

On the way to the boiler, the water passes to the water-level indicator, which is explained in detail in the following paragraph, and then to the *feed-water heater*. Over the water pipes in the feed-water heater the exhaust steam from the engine is passed. In this way

much of the otherwise waste heat of the exhaust is given back by heating the water before it reaches the boiler, resulting, of course, in a saving of fuel. The feed-water heater also serves as a muffler for the sound of the engine exhaust.

The *water-level indicator* is for the purpose of showing the operator the amount of water in the boiler. It consists of three tubes, Fig. 52, *M*, *N*, *O*, which are brazed together. The middle one *N* is a part of the water column, that is, its lower end connects with a pipe leading

Fig. 52. Diagram Showing Stanley Low-Water Automatic Valve with Three-Tube Indicator Body

to the bottom of the boiler and its upper end is in communication with the top of the boiler, so that the water stands in this column at the same height that it does in the boiler. At the lower end of tube *N* is the low-water try cock.

Tube *M*, at the left, is part of the water system from the pumps to the boiler and, when the car is running, water is constantly passing through it. The standpipe *O* is closed at its upper end and at its lower end is connected by a copper tube to the glass water glass on

the dashboard in front of the driver. The standpipe, tube, and glass form a U-tube which is filled with water, the level of which, when cold, stands about an inch above the bottom of the glass.

If the water level in the boiler, and therefore in the tube *N*, is above the top of the standpipe *O*, the cold water passing through *M* on its way to the boiler will keep the standpipe *O* comparatively cool, and the water in the glass will show about an inch above the bottom; but if the water in the boiler falls below the top of the standpipe, it will no longer keep cool and the resulting heat will turn some of the water in the standpipe into vapor. Since the end of the standpipe is closed, the pressure of the vapor will cause the water in the glass to rise, showing the driver that the water in the boiler is getting low.

It is important to remember that when the water is *high* in the glass it is *low* in the boiler. It should also be noted that the glass gives the correct reading only when the car is running, and that when the boiler is cold the water in the glass will be at the bottom whether the boiler is full or empty. A false reading of the glass may also occur from the heating-up of the indicator body when the car is left standing with steam up. This will make the water rise in the glass, apparently showing the water to be low in the boiler even though it were full. Directly upon starting the car, water will be pumped through tube *M* and the indicator body will cool down, giving a correct reading in the glass.

To fill the standpipe, U-tube and glass with water, the plug is removed from the top of the standpipe and water is poured into the glass faster than it can flow out of the standpipe. When all the air has been forced out in this way, the screw is replaced while the water is still running, but is screwed down only lightly. The water is then shut off and, when the level in the glass has gone down to about an inch above the bottom, the screw in the top of the standpipe is tightened up.

In freezing weather an anti-freeze solution should be used in the U-tube and glass. This can be made of equal parts of glycerine and water or of alcohol and water. A test of the indicator can be made when steam is up by opening the low-water pet cock until the water rises in the glass and then pouring cold water over the body of the indicator, which should cause the water in the glass to fall.

When the boiler is cold the amount of water in it is determined by opening the low-water pet cock. If water flows it shows that there is enough in the boiler to allow firing up. If no water comes and a wire run in the pet cock shows that it is not stopped up, water should be pumped in the boiler by hand. When trying the water level by the pet cock the water should be allowed to run several seconds so as to be sure that it is not merely the condensation which may have gathered.

If dirt or incrustation should stop up the lower end of the water column, it would cause false readings of the indicator and try cock. It is therefore important that this be guarded against by *blowing down* the boiler regularly. The procedure in blowing down will be referred to later.

Another protecting device of the Stanley is the low-water automatic valve, which in its action and location is closely connected to the water-level indicator. The purpose of this valve is to shut off the fuel supply in case the water becomes low in the boiler. As shown in Fig. 50, it consists of a valve B in the fuel line, an expansion tube D and two rods C, the latter forming a framework or support.

When the water in the boiler and water column gets below the try cock, the expansion tube D fills with steam and the heat of this steam causes the tube to become longer. This expansion moves the valve stem E, connected to the end of the tube, and this closes the valve, shutting off the fuel to the burner.

In case the low-water automatic valve closes, first make sure that there is water in the main tank, and that the pumps are working properly. Then with both by-pass valves closed run the car as far as it will go. By this time the pumps probably will have delivered enough water to cover the bottom of the expansion tube, allowing the fuel valve to open again. If not, the engine can be run with the wheels jacked up or water can be pumped by the hand pump.

There are four other accessories to the Stanley and other power plants, which have not yet been mentioned: the safety valve, steam gage, siphon, and oil pump.

The *safety valve* is connected to the boiler and will blow if the steam pressure exceeds the amount for which the valve is set. The *steam gage* is placed on the dash and indicates the steam pressure in pounds per square inch. The steam itself does not actually enter

the gage, but the pressure in the system is communicated to the gage by means of a tube filled with oil, which will not freeze in winter.

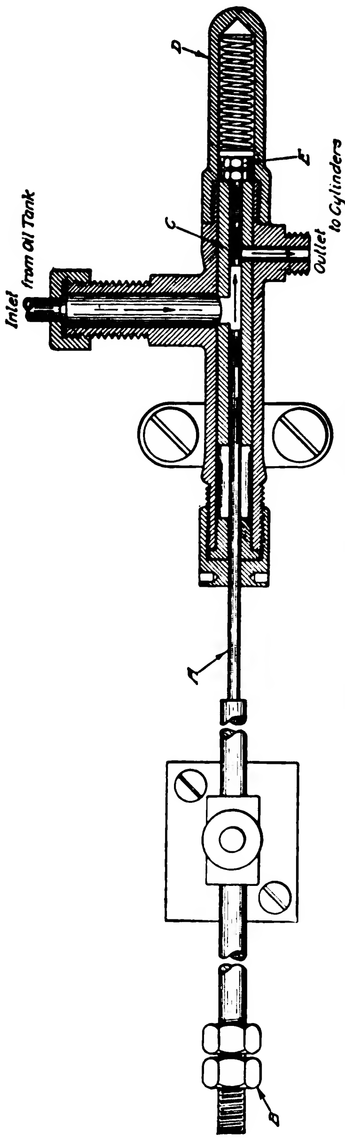

Fig. 53. Cylinder Oil Pump Used on Stanley Steam Cars
Courtesy of Stanley Motor Carriage Company, Newton, Massachusetts

When it is desired to draw water from a water trough or some other place from which it cannot be run into the tank from a faucet, the *siphon* is used. This is a hose, a branch of which is connected to the steam system by a hand valve. One end is placed in the tank-filler opening and the other end, which is provided with a screen, is put in the supply of water. The steam is turned on and, due to an injector action, draws the water up into the tank.

Driven by the same mechanism which drives the Stanley fuel and water pumps, is the *oil pump*, Figs. 46 and 53. From the oil tank the pump forces the oil through the sight feed on the dash, from which it is led into the steam line to the engine.

In the oil pump, Fig. 53, the plunger *A* is set in its extreme foreposition, so that the end will just come to the outlet. This is done by removing the delivery stub cap and delivery check ball and inserting a small wire in the outlet. When the driving crosshead is in the extreme position, the plunger should come to a point where it will strike the wire; the lock nut *B* is then tightened. This adjustment should be looked to if the position of the driving crosshead becomes changed.

To vary the amount of oil pumped, the distance between the end of the adjusting piston *C* and the pump inlet is varied. The shorter this distance the less the amount of oil pumped. The adjustment is made by removing the cap *D* and adjusting the set nut *E*. If the oil tank is allowed to run dry the pump may become air-locked, and it is then necessary to disconnect the copper pipe and work the pump until the air is expelled.

All ordinary steam-cylinder oil is not suitable for use in these engines because of the high degree of superheat. The Stanley Company recommend either the "Harris superheat steam-cylinder oil" or the "Oilzum high-pressure superheated steam-cylinder oil". Other makers recommend different classes of oils best suited to their particular engines and these will be noted later.

Now that a general idea of the make-up and operation of the power-plant accessories has been given in the description of the Stanley layout, attention will be turned to the characteristics of the accessories offered by other makers.

Doble. The details of construction of the Doble combustion chamber and boiler have already been shown in Figs. 35 and 41, and discussed on pages 34 and 40. The water level in the boiler is kept at the half-way point by an automatic by-pass valve, which is operated by the expansion of a regulator tube. As the water rises in the boiler, the tube is filled from an outside pipe with comparatively cold water. The decided change of temperature causes the tube to contract again, and the water is by-passed to the supply tank. The steam pressure is maintained around 600 pounds by another automatic device, which controls the fuel system.

From the upper headers of the generator sections, the live steam passes into a manifold which leads it through the throttle valve and then to the engine. From the engine, it passes back to the condenser, being forced along by the following steam.

A non-rusting alloy is used for the seats of the throttle valve. The valve, shown in Figs. 28 and 29, is a compound design, being a combination of a poppet and piston valve. The piston portion regulates the flow of steam, while the poppet serves to keep the valve in a tight, or non-leaking, condition.

The force of the steam constantly coming from the engine causes the steam to pass from the top to the bottom of the radiator condenser

and, under normal conditions, the steam has been completely condensed to water before it reaches the bottom. This water of condensation enters the water tank very near the bottom, so that any steam which still remains will be condensed as it bubbles up through the tank. Rapid acceleration from a slow speed or very hard slow pulling are the two conditions under which some steam may remain uncondensed in passing through the radiator. As a safety measure, in case of a very long stretch of slow heavy pulling, the water tank is provided with a vent at the top. With this condensing system, it is said that a car will run 1500 miles on one filling of water.

Doble Lubrication. Another one of Doble's departures from standard steam-automobile practice is in the matter of lubrication. The throttle, engine valves, cylinder walls, water pumps, and interior of the generator are all lubricated by regular gasoline-engine oil instead of the heavy steam-cylinder oil used in power plants.

This comparatively light mineral oil at once forms an emulsion with the water, due to the shaking up from the roughness of the road and the agitation of the feed water as the condensation enters the tank from the radiator. The oil, therefore, is sent into the generator along with the feed water and gives the interior of the tubes a very thin coating of lubricant. How thin this is may be judged by the statement that the generator temperature is 485° F. at the working pressure of 600 pounds. This coating not only prevents the tubes from rusting, but keeps scale from forming as it cannot stick to a greasy surface. The oil in the water also prevents scale from forming in other places and pipes, for it coats each particle of lime, etc., which may be thrown down and keeps it from sticking to any other particle and building up a deposit. It is this same oil that is carried over with the steam that lubricates the throttle valve and cylinder parts. The condenser saves the oil supply as well as the water, so that the lubricant is used over and over again, and a car is said to run 8000 miles on one gallon of oil.

Steaming Test. One of the main features claimed for the Doble design is the short length of time required to raise steam to a working pressure, that for ordinary running being 600 pounds per square inch. The following test was recently given out by the company.

The generator had approximately 150 square feet of surface and contained, when the water was at its normal level, 8½ gallons. Com-

bustion started with the water in the generator at 66° F. The first trace of steam came in forty seconds.

Pressure lb. per sq. in.	Elapsed Time	Pressure lb. per sq. in.	Elapsed Time
Trace	40 sec.	700	3 min.
100	1 min., 20 sec.	800	3 min., 10 sec.
200	1 min., 45 sec.	900	3 min., 15 sec.
300	2 min., 10 sec.	1000	3 min., 20 sec.
400	2 min., 25 sec.	1100	3 min., 25 sec.
500	2 min., 40 sec.	1200	3 min., 30 sec.
600	2 min., 50 sec.		

Ofeldt. *Fuel, Water, and Steam Connections.* Fig. 54 gives a clear idea of the fuel, water, and steam connections of the Ofeldt

Fig. 54. Diagram of Connections for Ofeldt Boiler Feed and Fuel Systems
Courtesy of F. W. Ofeldt & Sons, Nyack-on-the-Hudson, New York

system, the burner and boiler of which have been described previously. The feed-water pump *A* and the fuel pump *e* are usually on opposite crossheads of the engine, but to make the two systems clearer they have been separated in the diagram.

The Ofeldt Company makes these accessories either for use as a complete system, as shown in the diagram, or for use with other units. The company does not make a complete automobile.

An expansion tube N is the basis of the Ofeldt water regulator. This tube stands at right angles to the middle point of the boiler water column P, and when the water becomes low enough in the boiler and column for the tube to fill with steam, the expansion causes the closing of the water by-pass valve through the movement of the linkage O, M, L. When used with the Ofeldt water-tube boiler it is claimed that a water-level glass is unnecessary.

Fuel regulation is accomplished by the diaphragm valve, *w*. This is made up of two concave discs with a steel diaphragm fastened between them. Combined with the upper disc is the valve controlling the fuel supply. When the steam pressure on the lower side reaches the point for which the valve has been adjusted, the diaphragm pushes upward, shutting off the fuel. Upon the decrease of the steam pressure, the natural spring of the diaphragm again opens the fuel valve. Where used with a pilot light the closing of the valve completely shuts off the fuel to the main burner, but where no pilot is used just enough fuel is allowed to pass to keep the fire burning.

Automatic Fuel Feed. Possibly the most interesting of the Ofeldt accessories is the automatic fuel feed *i*, in which a spring is used to keep the fuel under pressure. It consists of a brass cylinder, 18 to 36 inches long and 4 inches in diameter, which is plugged at one end and capped at the other. Running the length of the cylinder is a coil spring with a piston at one end. The engine fuel pump *e*, or hand pump *d*, forces the fuel into the tank, pushing back the piston and compressing the spring. This spring keeps the pressure on the fuel the same as is done by the air tanks in the Stanley system. As part of the pressure layout is a safety or by-pass valve J, which can be set for the desired pressure on the fuel, the excess fuel from the by-pass valve and from the leakage past the piston in the regulator are returned to the fuel tank.

MANAGEMENT AND CARE OF STEAM CARS

In the preceding description considerable has been said as to the management and care of the units, but in this section some further hints will be added on the operation of steam automobiles.

Management on the Road. As will be understood from the foregoing, the operator's part in managing the power plant—other than attention to the throttle—is ordinarily limited to watching the water-

level indicator and managing the by-pass valve—if not automatic—in accordance with the water level. When the level drops, the by-pass valve must be closed, thereby causing all the water pumped to enter the boiler. When the water level exceeds the proper height, the by-pass valve is opened and water ceases to enter the boiler. It is not practicable to open the by-pass valve part way, as this would cause the water to go through the valve at boiler pressure and, in time, the scouring action due to the pressure would make the valve leak.

Blind adherence to the above rule will not always give as good results as may be obtained through manipulation. For example, if one sees a hill ahead, he can fill the boiler somewhat higher than its usual level and give the added water time to get hot before the hill is reached. This affords a reserve supply for surmounting the hill. In the average hilly country, one can make a practice of pumping water on down grades when little or no steam is being used and the heat of the fire is available to heat the incoming water. Near the bottom of the hill the by-pass valve is opened and the ascent taken in good style. If the accumulated pressure has caused the fire to shut off, the throttle may be opened just before the bottom of the hill is reached, and the drop in pressure will bring the fire on while impetus is being gained. It is a general rule for all classes of steam cars that *the fire should, if possible, be "on" before an up grade is begun.* By proper management the fire may be kept burning continuously in a hilly country, while power is used only on the up-grades.

In applying the above principles it should be remembered that only the wetted inside surface of the boiler is available for making steam. If the water is low, steam cannot be raised as rapidly as when the boiler is full, assuming that the water is hot in both cases. On the other hand, if the boiler is worked too full one may get wet steam despite the superheater, with loss of power due to condensation. In an extreme case, enough water might even be carried through to choke the clearance spaces at the cylinder ends. This would probably result in a head being knocked out or a connecting rod or crank bent, as the water could not be ejected quickly enough by the lifting of the slide valve to save the engine from severe shock when the piston reached the end of its stroke. A boiler of the Lane type, in which the water is partly converted into steam in coils above the

boiler proper, and in which the fire tubes are large enough to permit combustion to take place inside of them, is an exception to the above in that superheating takes place chiefly in the "boiler".

The more rapidly fuel is supplied to the burner, the hotter will be the fire. Where ample power is desired, therefore, the burner is worked under more than ordinary pressure. In the Stanley cars which carry pressure only in the auxiliary tank, 120 to 140 pounds is recommended.

Firing-Up. The following remarks apply particularly to cars with the Stanley type of burner and boiler. In the case of the Doble car, the constructions are so different that many of the instructions will not apply. The Doble system has been described in detail in the preceding pages, and the reader is referred back to these paragraphs for the firing-up of the boiler, etc. As will be explained later, it is customary at the end of a run to *blow down* the boiler for the purpose of ridding it of whatever sediment may be present. The blow-off valve is shut when a few pounds of pressure still remain, and the condensation of this remaining steam should suck the boiler full of water, *provided* the by-pass valve is closed. The presence of this water is desirable to protect the superheating coil when the fire is started. Therefore, if the car has a conventional fire-tube boiler with superheating coil beneath, the first step is to ascertain whether the boiler is actually full. Close the by-pass (if open), open the upper try cock, and if no water comes out, work the hand pump. See that the water tank is full. Open the throttle and the drip valve on the steam chest and continue pumping by hand till water comes out. Leave them open while starting the fire, to allow the water to expand.

If there is no pressure in the fuel tank, pump it up to the minimum working pressure by hand. Heat the pilot, either by burning gasoline in a cup, by an alcohol wick, or by the modern acetylene torch, as the case may be. When thoroughly heated, slowly open the pilot-light supply valve. If a blue flame does not result, close the supply valve and admit more gasoline to the cup.

After starting the pilot light, allow it to burn till the vaporizer is hot, then open the main-burner valve carefully. If it fires back into the burner, shut it off, wait a minute or two and try again. Turn the burner to full height gradually. If the flame is yellow or smoky, it is not getting enough air; if it is noisy and lifts off the

burner, it is getting too much air. Once adjusted for a given fuel pressure, the nozzle or air shutter should not need changing.

While the water is getting hot, the oiling up can be attended to. As soon as the pressure begins to rise, water will issue from the drip cock on the steam chest. Close this cock and the throttle valve as soon as clear steam comes out.

When pressure reaches 100 or 200 pounds, get into the car, throw the reverse lever to its full forward or backward position, open the throttle slightly and then close it at once. Repeat till the engine starts. With some yards of clear way, work the reverse lever back and forth with the throttle open only a crack, so that the car "seesaws" slowly. This will work the water out of the engine and warm up the cylinders till the entering steam ceases to condense. This process must not be hurried. An attempt to cut it short is likely to result in damage to the engine. As long as water is present the engine will run jerkily. When it runs smoothly the car is ready to start.

On starting, the first few blocks should be run slowly to complete the warming-up process. If the air pressure is below normal the air pump should be kept going.

At the End of a Run. On finishing a run, the boiler should be blown down with the fire turned off. This should be done by opening the blow-off valve near the bottom of the boiler. The escaping water will carry with it all the mud and precipitate that have accumulated. Close the blow-off valve at about 100 pounds, and the subsequent condensation will fill the boiler by suction from the tank. If the water in the tank is covered with oil, the end of a hose should be inserted and the tank flushed out to get rid of the oil. It is a good plan to put a cupful of kerosene into the tank. It will not only loosen whatever oil may be clinging there, but will help loosen the scale liable to form from hard water.

A thermostat water-level indicator operates only when steam is up. When the boiler is cold it indicates high water whether water is present or not. When the car is running, a faulty reading of the water level is usually soon noticed, and if it is overlooked there is still protection of the fusible plug. If, however, the boiler should be fired up with no water in it, the fusible plug would melt without the fact being heralded by escaping steam. Therefore, the fusible plug, like the water-level indicator, is useful only when steam is up.

Engine Lubrication. For the older cars not using superheated steam, the regular power-plant steam-cylinder oil is usually recommended. This is a mineral oil mixed with tallow to make it hold on the wet cylinder walls. It often contains graphite. This type of oil will not stand the high temperatures of superheated steam, and special oils must be used. As an example, the Stanley Company has recommended either "Harris superheat steam-cylinder oil" or "Oilzum high-pressure superheated steam-cylinder oil". The Doble uses the same kind of gasoline-engine oil as is used by the ordinary motor-car driver. Other engines use different grades of oil to the best advantage, and it is best in each case to find out the maker's recommendations.

The Fusible Plug. If the fusible plug blows out when the car is running, the escape of steam may be shut off by closing a valve usually interposed between the boiler and the plug. The fire should be shut off at once and, if possible, the car should be run to reduce the pressure, thereby allowing the boiler to cool somewhat. When the drop in pressure compels a halt, close the by-pass valve and pump water in by hand till it shows in the lowest try cock. Then, after replacing the fusible plug, the fire may be relighted and the water level restored while the car runs.

If the plug blows simply because the by-pass valve has been open too long, the by-pass can be closed, the main fire shut off, and the engine run by jacking up the rear wheels, till water shows in the lowest try cock.

Causes of Low Pressure. Low pressure is generally due to insufficient fire. If the burner pressure is low, steam will not be made rapidly. If the burner pressure is all right, the burner nozzle may be clogged or the vaporizing tube may be choked with carbon. The nozzle may usually be poked out with a bent wire without turning off the fire. If, however, the vaporizer is clogged it will have to be removed when the car is cold and cleaned, with a drill or otherwise, as the makers direct.

Occasionally the valve controlled by the diaphragm regulator may be choked, and rarely the main-burner valve. Either can be cleaned by disconnecting and running a wire through.

Occasionally the pilot light may clog in the same way, usually at the nozzle. The remedy is the same as for the main burner.

If the air pump fails to raise the pressure on the fuel tank to

the required degree, it is probable that the intake or outlet check valves leak. If, as is likely, they have oil on them, the oil may have gathered dust. The valves should be taken out and cleaned, and a drop of oil put on them to make them tight.

The various packings about the engine and auxiliaries require occasional tightening, and once in a while new packing is necessary. If the new packing is soft, like wicking, it may be put on top of the old, otherwise the old must be removed. The packing should not in any case be tighter than necessary to prevent leakage, for unnecessary friction would thereby be caused. A slight leakage about the water and air pumps may be permitted to save friction. As the hand pumps are rarely used their packings can be looser than those of the power pumps.

Scale Prevention and Remedies. In sections where hard water is used, the subject of scale is a serious one, and its treatment will depend on the character of the mineral contained in the water. Frequently it is possible to precipitate the mineral before putting the water into the tank. Sometimes the addition of a small quantity of lime will do this, sometimes carbonate of soda or "soda ash". Still other waters are successfully treated by adding caustic soda. Sometimes the simple addition of kerosene to untreated water will loosen the scale as above indicated. If these remedies are not successful, the user is advised to send a sample gallon of water to a maker of boiler compounds and have it analyzed, after which a suitable compound can be recommended. Scale allowed to accumulate by neglect is not only very detrimental to the boiler by interfering with the free flow of heat, but it also seriously reduces the steaming power. Instances have been known of the steaming capacity of boilers being reduced fifty per cent or more by scale. At the same time the shell and tubes get hotter than they should, resulting in unequal expansion and leakage.

Filling the Boiler. Before firing up, be sure that the boiler and superheaters are full. To be sure of this, open the throttle valve and steam-chest drip, close the by-pass valve and work the hand pump until water comes from the steam-chest drip. If more convenient fill the boiler from the town supply by means of the coupling furnished for this purpose, connecting to the blow-off valve. Never light the fire until you are sure that the boiler is full.

At the end of a run open the blow-off valve at the front of the boiler, and blow down to about 100 pounds. Fill the water tank and close the by-pass valve, and the condensing steam in the boiler will siphon the boiler full. Before blowing down, see that the pilot light is out, as well as the main burner. It can be extinguished by blowing into the pilot mixing tube.

Raising Gasoline Pressure. If the pressure tanks are empty and the pressure zero, proceed as follows:

Open the hand gasoline-pump valve and work the pump till the air gage registers 10 or 15 pounds. Tank 2, Fig. 47, is now full of gasoline, and tank 1 is full of compressed air. Attach the hand air pump to air valve and pump air into tank 1 till the gage indicates 80 or 90 pounds, which is the working pressure for the burner.

If now the fire is lighted and the car stands still, the pressure will gradually drop, but may be raised in a moment by working the hand gasoline pump. When the car runs, the power pump maintains the supply.

The air in tank 1 is gradually absorbed, and additional air is required. This is indicated, first, by the vibration of the air-pressure-gage needle when running; second, by a rapid drop of pressure when the car stands still. In case of doubt whether the drop is due to lack of air or to a leak in the automatic or pump valves, close the pressure-retaining valve. If the pressure still falls the air is insufficient.

Occasionally empty the pressure tank by opening valve *D*, and refill in order to determine definitely the amount of gasoline in it.

If the car is to stand some time with pilot burning, close the pressure-retaining valve to prevent the gasoline from leaking back through the valves and automatic. Be sure to open again on starting.

General Lubrication. On page 60, are mentioned the different grades of oil suitable for cylinder lubrication in the various types of engines. The lubrication of the cylinder walls and valves, however, is not the end of the subject, for, wherever there are two moving surfaces in contact, there must be lubrication in order to keep the friction losses at a minimum. Useless friction in the running parts of the engine and chassis of the car means an increased consumption of fuel. This, however, is often of secondary consideration in comparison with the wear and resulting repair bills, often caused by lack of lubrication. When a bearing becomes dry, it usually heats up and expands, and

in case this is continued to the point of "freezing", the car may be completely disabled on the road.

Of course all parts of the car do not have the same amount of motion and, therefore, do not require the same amount of lubrication. All makers of cars issue instruction books for each model and, when possible, the operator should provide himself with a copy and follow the oiling instructions. This, however, is often impossible, and it is then a matter of good judgment based on the known requirements of other cars. Outside of the power plant there is no particular difference between the construction and care of a steam- and a gasoline-engine driven car, and the lubrication chart of any of the later makes can be safely followed.

In the modern Stanley and Doble types, the crankshaft, cross-head, and other moving engine parts, other than piston, together with the rear-axle bearings, are all lubricated by splash, the crankcase being thoroughly oil-tight. The level of this oil should be inspected every two months, although it will probably not need renewing that often. Some of the older cars require that the eccentric be given a squirt of oil daily, by a hand gun. It is a good habit to give all grease cups a turn-down each day.

Water Pump. If the water pump fails to work, first see if the tank is empty. In addition to this there are three other causes to which failure is mainly due, viz, (1) *The pump may be air-bound.* To remedy, open the by-pass valve and run the engine. The air will work out readily, since there is no pressure against it. (2) *The check valves may leak.* There are three check valves, one on the pump intake, another on the outlet, and the third at the boiler. The intake valve is the most likely to leak. Remove the valve cap and clean the valve ball and its seat, being careful not to scratch them. If the boiler check valve is leaking, it will permit steam to escape into the water tank when the by-pass valve is open. This valve can only be examined when there is no pressure. (3) *The pump packing may leak.* Tightening the packing nut generally suffices, but occasionally repacking is necessary. Do not screw the packing nut tighter than is necessary, as it causes needless friction; a slight leakage may be tolerated. In case the power pump fails, use the hand pump, first running with the main fire off till the pressure is reduced to about 100 pounds. After pumping, close the valve with the pump plunger in.

Gasoline Pump. In most respects the gasoline pump resembles the water pump. If it becomes air-bound, it can be primed by using the hand gasoline pump, which is much larger and, drawing through the power pump, will suck out the air.

The gasoline pump packing should not leak at all, as it is both wasteful and dangerous. The pump is so small that adjusting is seldom needed.

If the hand gasoline pump becomes air-bound, unscrew the valve, which is open when the hand pump is used, till it comes out. Press the thumb over the valve-stem hole when the pump plunger is pulled out, and lift it off when the plunger is forced in. Repeating this several times will expel the air.

If the hand gasoline pump and hand water pump work together, the packing nut on the gasoline pump should be just tight enough to hold the gasoline, and the water pump should have its packing so adjusted that the pump will run perfectly free.

To pack the gasoline pump, put in first a thin leather washer, then three of the special packing rings supplied by the makers, then another thin leather washer, and screw the stuffing-box nut only hand tight. Do not use a tool to tighten it, otherwise the plunger will cut out the packing.

Care of Engine Bearings. If the engine is regularly lubricated the bearings will seldom require adjustment. If the bearings show the slightest discoloration from rust they have been insufficiently oiled. Adjustments are made as follows:

The crosshead guides are taken up by screwing down the nut on the bolt holding the frame rods together. The crosshead balls must be under sufficient pressure to keep them from slipping.

The wrist pins are taper and are adjusted with a screw held by a lock nut. First loosen the lock nut, turn up the screw till it stops, then back it one-eighth turn and tighten the lock nut.

The crankpin ball bearings are adjusted by removing the bolt, taking out the plug, and reducing it slightly by filing. When correctly adjusted the bearings should have no perceptible play.

The main bearings and eccentrics can only be adjusted after the engine is taken out of the car. They are adjusted to take up lost motion by filing or grinding down the face of the bearing cap, which must be very carefully done.

Be sure the engine-frame hangers are properly adjusted. Should the nuts work loose, the front end of the engine will sway, to the damage of the engine case and gears. In adjusting the engine-frame hangers do not set them up so tight that they will not swivel around the rear axle. If necessary insert shims of paper or thin brass, removing the rear engine case to gain access.

Operating the Cut-Off and Reverse. In the more recent Stanley cars the cut-off is variable from one-quarter to one-half stroke. On the engine is a quadrant from which the reverse lever works in connection with the reverse pedal. The quadrant has one notch, into which a dog attached to the reverse lever drops when the engine is "hooked up", that is, operating on short cut-off. To hook up the engine, press on the reverse pedal only. To release the dog, press a pedal beside the reverse pedal, called the *clutch pedal*. This releases the reverse pedal and a spring pulls it back, allowing the engine to cut-off at half-stroke. The car should always be started with the reverse pedal released, and the cut-off should not be shortened until the engine attains good speed. If it operates jerkily, release the reverse pedal by pressing the clutch pedal.

Care of the Burner. If the car does not steam well, look at the fire first. See that the gasoline pressure is not below 100 pounds.

If the pressure is right, the gasoline line may be clogged in the automatic valve, vaporizer, burner nozzle, or main-burner valve. If the burner has two mixing tubes, see if both sides are affected; if so, the trouble is probably in the automatic valve. If the two burner flames are unequal, the trouble may be in the vaporizing tubes or the nozzle, more likely the latter. Clean the nozzles by running a small wire through them with the screw out, or by using a bent wire without removing the screw.

If the vaporizing tubes are clogged, uncouple at the back of the burner, take out the bundle of wires from the tubes, and clean the tubes and wires thoroughly, using the bundle as a swab. Extinguish all fire before beginning.

If the pilot-light nozzle becomes clogged, use a screwdriver to turn the horizontal nozzle screw back and forth. A wire projects from this screw through the nozzle orifice and turning the screw causes the wire to clean the nozzle. Do this only with the pilot burning.

To regulate the air received by the pilot, bend the pilot vaporizer tube slightly away from the mixing tube for more air, or inward for less air. The pilot should burn with a blue flame slightly tinged with yellow, and may be adjusted while lighted.

Never use a reamer for cleaning either the pilot or main-burner nozzle, as it is likely to enlarge the hole, which is that of a No. 62 drill.

Sometimes after the automatic valve closes, the gas pressure at the nozzles will reduce gradually, causing the burner to light-back. When next the automatic valve opens, the fire will burn inside the mixing tubes with a roaring sound. This sound should be the instant signal for closing the main-burner valve and allowing the mixing tube to cool.

If the burner should fire back frequently and with a sharp explosion, it would indicate either a leak in the burner or a leak of steam in the combustion space. To test for a steam leak, first get up steam pressure, then take off the burner and examine the boiler, then run the front wheels against something immovable and open the throttle valve to see if steam escapes from the superheaters.

To Adjust the Throttle. If the throttle valve leaks it must be reground or a new valve substituted. It may, however, appear to leak owing to improper adjustment. There should be some tension on the valve stem when the lever is locked in the closed position. There is a distance rod running from the body of the throttle valve through the dashboard close to the throttle-valve stem. To increase the tension on the throttle, adjust the nuts on the distance rod.

To Adjust the Automatics. To carry a higher steam pressure, screw the adjusting screw on the automatic valve further in; for a lower pressure, screw it out. The same regulation of the gasoline relief valve will produce similar variations of the fuel pressure.

To Lay Up for the Winter. Run the car, on the road or with the rear wheels jacked up, till everything is hot, then extinguish the fire and blow off the boiler. While steam is escaping, open the safety and siphon valves and take out the fusible plug to clear them of water. Empty the tank, take off the caps of the check valves, and blow into the suction holes to clear the water from the checks ahead. Take off the water indicator and empty it, unless it is filled with non-freezing mixture.

General Remarks on Operating. The commonest fault of Stanley operators is opening the throttle too abruptly on starting. This is bad enough if the cylinders happen to be clear of water; if they are not clear, the results may be destructive. Always start slowly, and do not come up to road speed till the engine runs smoothly.

Never open any of the valves more than two or three full turns. They are screw valves, and if turned a dozen or more times they will come clear out.

Practice reversing where you have plenty of room. The ability to look and steer backward while operating the reverse pedal and throttle is not a natural gift. After reversing, be sure that the pedal has been released, by pressing the clutch pedal before giving steam.

FIRE ENGINE AND HOOK-AND-LADDER TRUCK EQUIPPED WITH CHRISTIE FRONT-DRIVE TRACTORS

COMMERCIAL VEHICLES

INTRODUCTION

Development of Field. While the development of the commercial car was slow at first owing to the numerous shortcomings of early types, it has advanced with wonderful rapidity during the past few years and bids fair to supersede, in a comparatively short time, the use of the horse-drawn vehicle for business purposes, not only in the large cities but also on the farm. As in the case of the pleasure car, Europe led in the development of the automobile for transportation purposes, chiefly with military necessities in view, as without power-driven vehicles it would be impossible to move the enormous food and ammunition supplies required by an army of present-day proportions. However, American manufacturers have advanced so rapidly in the production of commercial cars during the past few years that in 1916 the registration of New York City alone showed a greater number of these vehicles than were reported by the census of 1915 for the whole German Empire and more than half the number reported in service in Great Britain during the same period.

Scope of the "Commercial Vehicle". It is important to know the reasons for the revolution which is now in active progress, as well as to become familiar with the prevailing practices in America and abroad in the construction, operation, and maintenance of that large and varied class of automobiles employed exclusively for business purposes. Regardless of type, class, or method of propulsion, these are commonly referred to as "commercial vehicles". This classification embraces not only motor delivery wagons and trucks for the transportation of merchandise, but also taxicabs, omnibuses, sightseeing vehicles, motor road trains, farm tractors, emergency repair or tower wagons for street-railway service, and also vehicles for special municipal service—ambulances, patrol wagons, fire engines, street-sprinkling and garbage-removal wagons, and the like. In fact, it may be said that any automobile not devoted to pleasure is a commercial vehicle, and, as was to be expected, the first types of these

vehicles were merely pleasure cars transformed to suit the needs of the occasion. To a certain extent, this still continues to be the case.

Standard Design. Whether it be electric-, steam-, or gasoline-driven, the general design of the motive power, as well as that of its transmission to the driving wheels, is practically the same in the commercial vehicle as it is in the pleasure car, except that the chain drive has now almost disappeared on the latter, and all the component parts—bearings, frames, axles, steering gear, and compensating mechanism—are the same. In other words, the chassis in both cases is composed of similar members. For the sake of brevity in the present treatise, it is assumed at the outset that the reader has become familiar with motor-car engineering so far as it relates to pleasure-car construction; that he understands, from previous study and the actual handling of machines, the *theory* of the operation of the internal-combustion engine; that he is conversant with the distinguishing characteristics of the several types of engines as well as with their advantages and limitations; and that he is acquainted with the types of transmission systems ordinarily employed on pleasure cars—in brief, that he understands any reference to component parts, to their functions, and to their relation to one another, without the necessity of explanation.

In common with the pleasure car, the commercial vehicle is capable of traveling at various speeds wherever road conditions will permit it to go. Both comprise in a single entity a wheeled vehicle suitable for transportation purposes, fitted with an independent, self-contained power plant, and both present the same engineering problems so far as they relate to the construction of the motor, its control, and the transmission of its power to the road wheels, the design of the running gear, and the control of the vehicle itself. Divergence in practice is encountered with the consideration of the purposes for which each vehicle is designed. The pleasure car is not intended to be a very efficient vehicle. Its carrying capacity bears a comparatively insignificant ratio to its total weight, and, usually, the car is not designed to work under the same severe and continued conditions of service that are the first requirements of the commercial vehicle. It must be capable of high speed with its maximum load of passengers and must combine reliability with endurance to an extent sufficient to meet the demands of its owner when on pleasure bent.

Classification. In order to make the subject as clear as possible and to facilitate reference on the part of the student, industrial motor vehicles as a whole have been classified, first, by their motive power; and second, by the uses for which they are intended. Thus there are, today, in the order of their relative importance:

Motive Power	Electric vehicles
	Gasoline-driven vehicles
	Gas-electric vehicles
	Steam vehicles
Types of Vehicles	Industrial electric trucks
	Delivery wagons
	Trucks, vans, and similar freight carriers
	Passenger vehicles—stages, busses, taxicabs, sight-seeing cars, etc.
	Municipal vehicles—patrol wagons, ambulances, fire apparatus, garbage-removal wagons, street sprinklers, etc.
	Special types—railway tower wagons, emergency repair wagons, farm tractors, road trains, etc.

This classification has been made advisedly, for, though kerosene and alcohol are being experimented with as fuels for the internal-combustion engine and particularly for commercial purposes, by far the greater majority of types marketed at present are driven by gasoline fuel.

Each of the foregoing principal divisions is susceptible of further subdivision, but this is neither necessary nor desirable. Commercial motor vehicles are now built for almost every conceivable purpose involving freight hauling or the transportation of passengers and include many special uses, such as hauling huge reels of telephone cable and drawing the cable through the underground conduits, transporting and hoisting safes and pianos, delivering coal with special dumping wagons, and the like. They differ only in the special equipment with which they are provided for the service in view, and, as their construction otherwise is the same, it would only lead to confusion to attempt to consider them separately.

ELECTRIC VEHICLES

Range of Use. Owing to the general recognition of its simplicity and economy, which has been brought about by a co-operative propaganda fostered by the electric lighting and power companies,

the growth of the use of the electric commercial vehicles during the past few years has been little short of phenomenal. One New York firm alone uses nearly 350 electric delivery wagons, several have nearly 100, while no fewer than forty-five have "fleets" of 10 cars or more. All told, there are several thousand electric vehicles in New York City and more than 100 garages and charging stations, while the demand for current has been so great that the minimum for charging batteries has recently been reduced to $10 per month. Current is supplied at a preferred rate under special contract, which calls for the charging of the batteries during those hours of the night when the load on the central stations is lowest.

Advantages of the Electric Type. *Simplicity.* One of the chief advantages of the electric vehicle, when judged from the purely commercial point of view, is its great simplicity, which, to a very large extent, solves the labor question that has proved such a deterrent to the adoption of the gasoline vehicle for commercial service. As the duties of the driver of an electric vehicle do not extend beyond its actual starting, stopping, and guidance while under way, anyone who has been accostumed to the use of horses can master its operation in the course of a few hours. This also appears to be equally true of men who have never driven any type of vehicle previous to their taking the wheel or steering tiller of an electric. Apart from the actual mechanical control of the vehicle, the driver's only other care is to keep informed as to the state of charge of the battery by watching the voltmeter, in order to prevent running the car with the batteries exhausted, as this is very detrimental to their continued usefulness. However, as the batteries of most commercial vehicles are charged every twenty-four hours and the car run is planned to lie within its traveling radius on a single charge, with a factor of safety allowed in addition, this is not a very onerous duty. The further requirement of noting the current consumption on starting and running, as indicated by the ammeter, in order that any defect in the operation of the running gear of the car may be detected and remedied, is also a very simple one, so that an unskilled driver is available at a correspondingly lower charge for labor cost in the operation of the vehicle. The adoption of the ampere-hour meter showing the actual consumption of battery energy has simplified the task of the driver still further.

Efficiency and Long Life. Broadly speaking, short runs with many stops are the province of the electric, so that probably 80 per cent of all average city deliveries come within its economic field. Its labor cost is much lower than that of the gasoline car, since an unskilled hand can operate it efficiently, while one man at the garage can take care of nearly twice as many electrics as of gasoline cars. The electric is easier on tires, owing to its reduced speed, insurance rates are lower, and its depreciation can be figured on a much more favorable basis, as it has been shown to have an average effective life of ten years. The fact that all its moving parts revolve has a most important influence on its low maintenance cost and reliability, many electric trucks showing an average of 297 days in service of the 300 working days in a year.

Power Efficiency. The amount of power available on a single charge of the batteries without unduly increasing the weight is so limited that in the design of the electric great care must be taken to eliminate friction and other sources of power loss at every possible point. This is further necessitated by the gradually decreasing efficiency of the batteries with age. Starting with 80 per cent when new, the efficiency may drop rapidly to 50 per cent or below unless the batteries are properly maintained, which is likewise true of the transmission efficiency of the running gear of the vehicle; so that while unskilled labor may be employed for the operation of the vehicles this is not the case where their maintenance is concerned. Power losses due to the tires are also an important factor, and as the pneumatic tire can very seldom be considered for commercial service, the same degree of efficiency is not obtainable from the business electric wagon as from the pleasure type employing the same motive power. Road conditions must also be considered—despite the fact that electrics are employed almost exclusively for city or near-by suburban service—as mud, snow, and ice in winter, and poor pavements at any time cause an increase in the current consumption.

ELECTRIC DELIVERY WAGON

General Specifications. Whether considered from the point of view of design and construction or from that of operation, the electric delivery wagon is, without doubt, the simplest vehicle in the commercial field. As already mentioned, its operation may be

mastered in a comparatively short time, either by the ex-horsedriver or by a person who has never had any experience in the control of a vehicle, so that the labor cost—always an item of importance in this field—may be materially reduced without fear of the equipment suffering in consequence. It is usually customary with manufacturers of these vehicles to adopt a standard form of design, which is employed throughout in every size listed by the same maker, the only differences being those of dimension, load capacity of the vehicle. and capacity of the battery to take care of the increased weight.

Package delivery wagons and express wagons of the electric type have a useful load capacity ranging from 1000 to 2000 pounds. though a very few of less than 1000 pounds' capacity were employed at first. The 40-mile run is standard and is based on an average speed of 10 to 20 miles an hour, including stops, as the necessity for frequently stopping and re-starting the car in delivery service has an important bearing on the mileage of which the car is capable on a single charge. The latter is naturally figured on the maximum efficiency of the car as a whole, so that in practice this is seldom fully realized, owing to the deterioration of the batteries in service.

Design. The electric has progressed through the stages represented by the angle-iron frame, the armored wood frame, and the modifications of the two as employed on gasoline cars to the now generally current type of pressed-steel frame. This frame has the advantage of being extremely strong for its weight. It is composed of side and transverse members produced in hydraulic presses directly from steel plates of about $\frac{5}{16}$-inch thickness, these members being riveted together and further reinforced by gussets at the corners. On account of the height of the vehicle, the frames are made perfectly rectangular and without either a drop or narrowing forward.

The types of suspension employed also show the same variations as are to be found in the gasoline-driven cars, some of the smaller electrics having the full elliptic springs ordinarily employed on wagons, while intermediate and heavy vehicles have either straight semi-elliptic springs front and rear or a half-platform type of suspension in the rear. A study of the Baker and General Vehicle types of delivery wagons and trucks will show how closely they approach, as a whole, to what is considered general practice in the automobile field.

Because of the heavy loads carried and of the fact that solid tires are used, the entire running gear has to be planned on a very liberal scale. This is likewise true of the springs. While it is desirable that the latter afford as much protection to the mechanism as possible, sufficient stability to carry the load is of more importance than flexibility, as the comparatively slow speeds do not occasion the violent shocks met with in the pleasure car.

MOTIVE POWER

Type of Motor. As already mentioned, the motive power of the majority of smaller electric vehicles consists of a single motor, and, in several makes, such as the Waverley, G.V., G.M.C., and Detroit, this practice extends to heavy units, with a corresponding increase in the efficiency of the vehicle as a whole. In order to keep down the weight as well as the space occupied, these motors are very small for their power output, and consequently have to be wound for high rotative speeds. They are usually of the series type of the General Electric or the Westinghouse make and are designed to carry heavy overloads for short periods, to enable the car to pull out of a bad place, to start with full load on a heavy grade, or to meet similar emergencies, the motor, under such conditions, delivering an amount of power greatly in excess of its normal rating.

Motor Suspension with Chain Drive. Since the use of spur-gear drives has decreased, the motor is usually suspended from the frame by means of transverse members riveted to the side rails and is placed near, or slightly forward of, the center of the chassis, in order to give the best distribution of weight. This is an advantage not obtainable when the motors are hung from the rear axle or too close to it. In view of the high speed at which the motors run—1800 to 2000 r.p.m. or more—a reduction in two stages is necessary to avoid the employment of excessively large sprockets. The first step is from the motor to a countershaft by means of a single silent chain of the Morse or the Renold type, the motor being suspended in such a manner that it may be moved a short distance one way or the other to permit the adjusting of this chain to the proper tension, Fig. 1. The large sprocket on the countershaft, which serves to cut down the speed in the proportion of about 1 to 5, also embodies a differential, or compensating, gear of the usual bevel or spur type, thus making

it possible to employ a solid one-piece axle instead of weakening the latter by inserting the balance gear in it. This is an important feature, as the rear axle must bear 60 to 70 per cent of the total weight of both the car and the load. From the countershaft, chains are run to each of the driving wheels. The relative positions of the countershaft and the rear axle are maintained by heavy adjustable radius rods, attached forward to the outer ends of the countershaft and, at the rear, to the axle. These rods take the stress of the drive off the

Fig. 1. Motor Suspension and Silent-Chain Drive on Baker Trucks

springs and counteract the tendency of the chains to draw the rear axle toward the countershaft, under the pull of the motor.

Motor Suspension with Shaft Drive. On light delivery wagons of the shaft-driven type, three methods of motor suspension may be noted. In the first method, the motor is placed just forward of the rear axle, its housing being practically integral with that of the axle. Either a worm drive permitting of a single-speed reduction or a two-speed gear through spur gears is employed. As the motor moves with the axle and their relations are fixed, flexible joints are not required. A modification of the first method consists in placing the motor under the car at about the center and mounting it on a flexible suspension so that it can move under stress without disturbing its alignment; while the third method provides for taking such stresses on universal and slip joints interposed between the motor and the rear axle.

Fig. 2. Chassis of 4000-Pound G. V. Electric Delivery Wagon

The relative locations of the various essentials of a delivery wagon of the single-motor side-chain-drive type are clearly shown in Fig. 2 that illustrates a G.V. chassis of 4000 pounds' capacity, this being the same except for the difference in size.

Worm-Gear Transmission. While the power is transmitted through a combination-chain drive, i.e., silent chain for the first reduction and roller chains for the final drive, on the majority of delivery wagons, the practice of utilizing the worm drive, which has recently been adopted on the pleasure cars, has also been taken up in this field on the light vehicles. An example of this is represented by

Fig. 3. Rear Axle of Commercial Electric Delivery Wagon

the G.V. 1000-pound delivery wagon, equipped with a single motor driving through a propeller shaft having two universals and with a David Brown (British) type of worm-gear rear axle. On machines of this class, it is customary to mount the motor on a flexible support, which permits it to adapt itself to variations in the angularity of the propeller shaft, thus reducing the load imposed on the universal joints and, at the same time, avoiding the effects of torsional stresses on the motor. As the location of the motor is such as to prevent the suspension of the battery below the frame in the usual cradle, it is carried forward under a bonnet, or hood, and the wheel-base of

Fig. 4. G.M.C. Chassis with Combination Shaft and Chain Drive

the chassis correspondingly lengthened. This is not the case with the Commercial worm-driven delivery wagon, as in this instance the motor is placed almost directly on the rear axle, as shown in Fig. 3, thus eliminating the propeller shaft and the necessity for universal joints. The spring suspension of the motor will be noted protruding above its forward end.

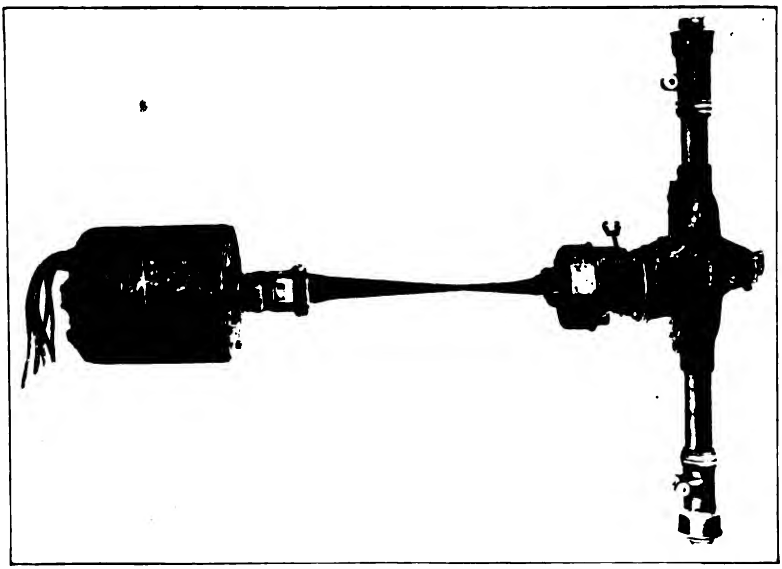

Fig. 5. Motor, Drive Shaft, and Jackshaft Assembly for G.M.C. Electric Wagon

Shaft and Chain Transmission. The G.M.C. (General Motors Company) electric embodies a combination of shaft and chain drive, as shown by the chassis, Fig. 4. This drive incorporates an ingenious

Fig. 6. Details of Motor Mounting, Brake, and Drive, G.M.C. Electric Delivery Wagon

feature consisting of the use of a spring steel shaft, as shown by the detail view, Fig. 5. The design of these cars, as shown by the chassis, is standard for all capacities ranging from a 1000-pound delivery

Fig. 7. Chassis of Waverley 5-Ton Electric Truck, Showing Battery Installation

wagon up to a 6-ton truck, and, in each case, the section of this shaft is calculated to transmit the power necessary, with a predetermined degree of flexure in starting, which serves to cushion the mechanism

as well as the tires. The pin attachment at the motor and the bevel-gear-driven countershaft eliminate the necessity for universal joints in this member while still permitting a rigid mounting of the motor on its sub-frame. As will be noted in Fig. 6, which shows the details of the complete drive, this sub-frame is carried in bearings on a tubular transverse member, thus allowing for relative movement in a longitudinal plane, the shaft itself compensating for torsional stresses.

Unit-Wheel Drives. Mention has already been made of the abandonment of two-motor drives on comparatively light cars, as well as the successful employment of a single motor on vehicles up to 5 tons' capacity, as in the case of the Waverley 5-ton chassis,

Fig. 8. Two-Motor Axle with Spur-Gear Drive, Commercial 2-Ton Truck

Fig. 7. The Commercial electric is an exception to this in that it shows the successful employment of two motors on cars as small as one-ton capacity. The rear axle of this car is a complete self-contained unit, as will be seen upon referring to Fig. 8 illustrating the drive of a 2-ton Commercial. The form of mounting employed is clear in the illustration, while Fig. 9 shows the details of the gear reduction between the motor and the driving wheel. This concern also makes a four-wheel drive, which is employed on vehicles of 3½ to 7 tons' capacity. On these machines, both front and rear axles are alike. One of them is illustrated in Fig. 10, in which it will be noted that the motor and the driving wheel are an integral unit pivoted in

the axle to permit of utilizing all four wheels for steering. The speed reduction in this instance is simply a double spur-gear train meshing with an internal gear cut on a drum in the rear wheel.

Couple-Gear Truck Drive. A particularly ingenious example of the ease and directness with which electricity lends itself to special

Fig. 9. View of Spur-Gear Reduction of Commercial Electric Drive

forms of construction is to be found in the drive of the Couple-Gear truck, so called because all four wheels are not only driven by electric

Fig. 10. Two-Motor Axle of Four-Wheel Drive of Commercial Heavy Trucks

motors but are utilized for steering purposes. These vehicles are built as straight electrics, using a storage battery as the source of

current; and as gas-electric vehicles, a gasoline engine and generator forming the power plant, the remainder of the design and construction being the same in both cases. Fig. 11 illustrates the detail of the axle design employed, each wheel being carried on a steering

Fig. 11. Couple-Gear Axle for Unit-Wheel Drive

spindle, and all four wheels coupled to act in unison, permitting the car to turn in a very short radius. The parts shown on the right-hand spindle in the illustration are the fields of the motor, the wind-

Fig. 12. Dismounted Couple-Gear Truck Wheel, Showing Motor Parts

ings being just visible in the armature tunnel. They are made in this form, as the motor is practically a part of the wheel.

The motor is built directly into the wheel, as will be apparent from the illustration of a dismounted wheel shown in Fig. 12. The

motor is of bipolar type, designed with flat fields in order that it may fit within the wheel without unduly increasing its section, and is held by its attachment to the axle. The wheel accordingly revolves about the motor, being driven by the two small pinions which are noticeable on opposite ends of the armature shaft and which mesh with the circular racks attached to the periphery of the wheel. The brushes are carried in a yoke bolted to the outer half of the field casting, so

Fig. 13. Walker Electric Chassis, Showing Combined Motor Axle

that the removal of the latter makes everything accessible. The cables for the motor current are led through the hollow axle. Apart from this feature and the employment of a four-wheel steer, the vehicle itself follows more or less conventional lines.

Balanced Drive. The transmission on the Walker cars, known as a "balanced drive", is another radical departure from current practice in this respect. These cars are built in capacities ranging from 750 to 7000 pounds and have been in successful service for a

number of years. As will be noted in Fig. 13, a single motor is employed, and it is built practically as an integral part of the rear axle, the housings of which form the fields. The armature of the motor is at right angles to the driving wheels, and its shaft is extended both ways to form the drive. At the outer ends, this shaft carries small spur pinions which mesh with two large gears. The latter,

Fig. 14. Details of Walker Electric Wheel Drive

in turn, mesh with an internal gear bolted to the inner face of the steel rims of the driving wheels themselves. The detail of this is made plain in Fig. 14, showing one of the wheels with the outer protecting disc removed. It will be apparent that this constitutes not only an unusually compact motor unit and transmission, having the great advantage of being always in direct line with its drive, but that it likewise dispenses with a differential, as the wheels themselves are balance gears.

CURRENT AND CURRENT CONTROL

Battery Equipment. As the motors commonly employed are wound to take current at 80 to 85 volts, the battery consists of 44 cells, divided into three or four groups of cells held in separate oak boxes, or "trays", as they are termed, to facilitate handling. This voltage is standard, regardless of the size of the vehicle, the latter being compensated for by changing the capacity of the battery. Thus, for light delivery wagons, each cell contains three positive and four negative plates of medium size, giving an 85-ampere-hour discharge capacity, while a 1000-pound wagon is equipped with a battery having nine-plate cells with a capacity of 112 ampere hours; a 2000-pound wagon, eleven-plate cells of larger dimensions, giving 140 ampere hours; and so on in accordance with the size of the vehicle and the load it is designed to carry. Most electric vehicles have the battery underslung, i.e., carried in a cradle supported from the frame of the chassis. The cradle is enclosed in a battery box for protection against mud and water and has hinged doors at the ends through which the battery may be introduced or removed. By this arrangement, the weight of the battery, which is the heaviest single item in the entire construction, is distributed evenly between the forward and rear wheels, which leaves the entire floor space of the wagon available for the load. In special types, such as the G.V. 1000-pound worm-driven delivery wagon, the usual practice in the pleasure-car method of carrying the battery under a hood forward is followed. All the wiring between the battery, controller, and motor is carried beneath the floor and is protected from injury by running it through iron conduits.

Controller. In the case of delivery wagons and light trucks, the controller itself is placed either beneath the seat or under the footboards and is similar in construction to those employed on street cars, but much smaller in size, owing to the low voltage and comparatively small amount of current to be handled. It is operated by a small hand lever and usually provides four speeds ahead and two reverse, all of which are obtainable by moving the same lever, although a special lock, or catch, must first be operated before the vehicle can be moved backward. This usually takes the form of a pedal, or kick plate, which may be depressed with the heel and must frequently be held down while reversing. When released, it auto-

matically returns the controller to the ahead position, in order to prevent the vehicle from being backed inadvertently.

Departures from the usual method of placing the controller are to be found in some of the medium-capacity vehicles, such as the Baker, in which the controller is located on the steering column just below the footboards; in the Urban, it is placed in a special dash compartment, the lever being on the steering wheel. This compartment also contains the ampere-hour meter, a type of instrument which records in watt hours the amount of power drawn from the battery and, at the same time, indicates the available amount remaining at any time. Ampere-hour meters are coming more and more into general use on both pleasure and commercial electrics, and a detailed description of the instrument and its use is given in connection with electric pleasure cars. In service, this dash compartment is protected by an aluminum plate through which the dial of the meter appears. On the Commercial, the controller is mounted directly on the steering column and is operated by a second smaller wheel, Fig. 15. The controller itself is thus above the footboards, and by the removal of the protective housing shown becomes very accessible. In cases where it is necessary to provide for handling heavy currents, a railway type of controller is employed.

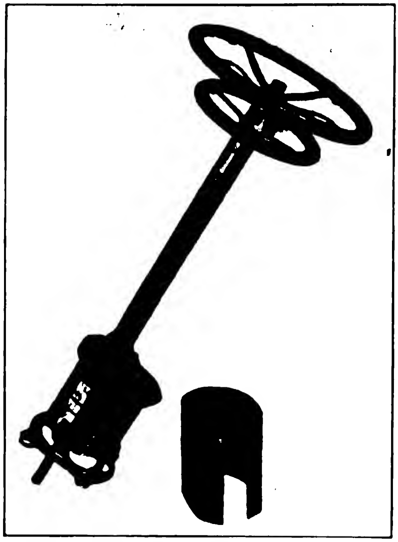

Fig. 15. Commercial Electric Controller on Steering Column

A novel controller installation that gives instant accessibility is found on the G.M.C., as shown in Fig. 16. The controller proper, as well as all wiring terminals, fuses, and meters are mounted under a short hood, the resistance being suspended just beneath the controller, while the charging receptacle is below the center of the bumper. This view illustrates the forward side of the dash, while Fig. 17 shows the side facing the driver. The connection between the control lever

over the steering wheel and the controller is through a shaft and a bevel gearing, as shown in Fig. 16. In the illustrations, this lever is

Fig. 16. Controller Installation of G.M.C. Electric Delivery Wagon

at the neutral position, successive movement from this point forward giving five speeds ahead and two reverse speeds backward. The

Fig. 17. Simple Control of G.M.C. Electric

G.V. control is equally compact, being mounted in a steel box forming the driver's seat, as shown in Fig. 18. The safety switch and

the plug connection for an inspection lamp are seen on the outside at the left. Inside are, first, the switch connections, then the fuses, and, next, the fingers of the controller. At the upper right hand (driver's left) is the control lever, while just visible below the box is the resistance.

Safety Devices. In view of the fact that the average driver of an electric delivery wagon or a truck is either a graduate from the reins or has had no experience in handling vehicles at all, it has become customary to provide safety devices which, to a large extent,

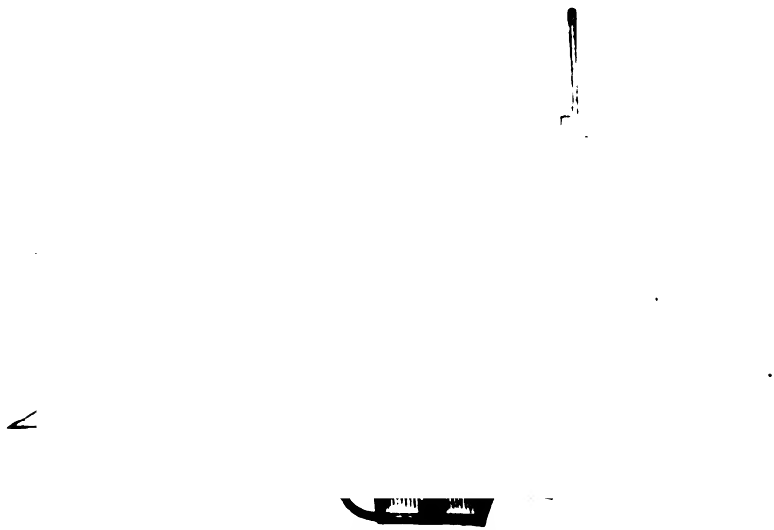

Fig. 18. Controller Box of G. V. Electric Delivery Wagon

prevent accidents that might otherwise result from this lack of experience.

Cut-Out Switch Connected to Brake. The brake is usually interconnected with a cut-out switch which automatically shuts off the power independently of the controller simply by the application of the former. While the brakes are sufficiently powerful to stop the machine even with the current on, forgetting to shut off the current would either blow out the fuses or result disastrously to the motor.

Circuit-Breaker and Hand Switch. A circuit-breaker is provided on some cars to obviate the necessity for frequent replacing of the fuses, this being the usual practice in street railway and other electric work. Frequently, a hand-operated cut-out switch is also installed

to permit of inspecting or working on the controller without the necessity of disconnecting the battery, as a failure to do so where no switch is provided is apt to result in painful burns, owing to the large amount of current.

Charging Circuit-Breaker. Another safeguard is an automatically operated circuit-breaker to protect the battery from being overcharged. This is used in connection with the Sangamo ampere-hour meter, which is described under the head of "Meters". Unlike the Anderson device described previously, which can be employed only where connection can be had to the field coils of the generator, this circuit-breaker operates exactly the same as the circuit-breaker in a generating station, which opens the line when an excess amount of current passes through it, except that in this case its operation is not controlled by the number of ampere turns on the circuit-breaker itself, but by a trip switch actuated by the ampere-hour meter when its dial records that the battery is fully charged.

Devices to Prevent Accidental Starting or Tampering. Devices are provided to prevent the accidental starting of the vehicle when not anticipated by the driver; also to guard against tampering by the ubiquitous small boy. On the G.V. 1000-pound worm-driven delivery wagon, for example, the emergency brake cannot be locked on except when the "running switch" is in either the neutral or the charging position, and cannot be released until thrown into the running position. Moreover, this switch can be thrown to the running position only when the controller is at the "off" point, or neutral position. The interconnection of the brakes and the controller "throw-off" allows the driver to use both hands for steering, in an emergency and, at the same time, to cut off the power and apply both brakes with his feet. This emergency-brake lock compels the driver to turn off the current by throwing the running switch to neutral when leaving the car; it also prevents the brake from being released by an unauthorized person, as the driver can take the switch handle with him. As the brake cannot be released until the switch is thrown on, the driver is reminded of that fact. The running-switch lock prevents the accidental starting of the vehicle, which might happen if the controller had been tampered with during the driver's absence, and if, upon his return, he threw the running switch on without first looking at the controller handle.

Brakes. Owing to the comparatively low speeds, the braking equipment in the earlier designs usually consisted of a single set of drums attached to the driving wheels. Against the inner faces of these steel drums bronze shoes were expanded by means of a pedal and the usual brake rigging beneath the car. As was the case in practically all early chain-driven cars, the braking drums carried the driving sprockets on their outer faces.

But in this, as in many other essentials, practice has been improved along the lines followed in the gasoline car. It is now customary to employ two sets of brakes, one for regular service and one for emergencies. Usually, both sets of brakes are carried in drums on the driving wheels, either side by side or concentrically, a friction facing of asbestos on a woven-wire foundation being employed. In some cases, the service brake operates on a drum carried on the armature shaft of the motor.

Tires. While solid rubber tires are most generally employed, they are not necessarily so, as pneumatic tires are to be preferred where the merchandise to be carried is of a light or fragile nature or where speed is one of the chief features of the delivery service. They not only reduce the liability to breakage, but also lessen the cost of maintaining the vehicle in repair. However, as there are comparatively few branches of commercial service in which the pneumatic tire is economically practicable, its use is very limited. The solid tires employed vary in size from two to four inches, and for weights in excess of the capacity of the latter, they are used in twin form on the rear wheels.

SPECIAL FORMS OF THE ELECTRIC

Electric Tractors. The huge street-cleaning or garbage-removal truck, shown in Fig. 19, is drawn by a 5-ton G.V. electric tractor, the combination being along lines somewhat similar to the front-driven electrics adopted by the Paris street-cleaning department for the same purpose, except that the latter have a two-wheel tractor and are fitted with a specially designed covered steel body. One use of the electric tractor built along the lines just referred to is shown by the Couple-Gear propelled steam fire engine, Fig. 20. Part of the battery is carried on the frame and the remainder is suspended beneath it, the power consisting of two Couple-Gear motor wheels

Fig. 19. Five-Ton G. V. Electric Tractor Hauling Garbage Wagon

mounted on steering spindles and operated by a street-railway type of controller which will be noted at the left of the driver. The entire power plant is a complete unit, which is bolted directly to the engine without further alteration than the removal of its front truck.

Fig. 20. Couple-Gear Tractor Drawing Steam Fire Engine

Industrial Trucks. One of the most important developments of the past few years has been the widespread adoption of the so-called industrial truck. In a broad sense, the term represents a classification rather than a type, as there are several different types of chassis built for this purpose. Probably the first of these to be placed in service was the Lansden dock truck, designed for handling cargo on steamship piers. In addition to this, there are baggage and mail trucks for use in railway depots, also truck cranes and tractor trucks, and it will be apparent that they are designed for service where no other form of power than electricity would be either convenient or permitted. The battery truck crane, the baggage truck, and the tractor trucks are merely modifications of the simple freight truck, their functions varying somewhat in each case. The baggage truck has a field of its own in the handling of baggage and mail, some being of the drop-frame and double-platform type and others having the battery and mechanism placed below the loading platform, which is made of railway-car height.

The simple industrial, or freight, truck is built in sizes and capacities suitable for moving loads on piers, in freight sheds, warehouses, factories, and industrial establishments generally. Its short wheelbase permits it to pass through congested spaces, going backward or forward with the same facility, while it is capable of ascending gradients of 10 to 25 per cent. On piers and at railway terminals it can deliver its load on the deck of a vessel or in a box car. The capacity of such trucks seldom exceeds 2000 pounds, this figure being found the practical limit for trucks capable of the widest range of action. The loading space of a truck of this capacity is 28 square feet, while the total area required for movement is only 34 square feet, the machine having an extreme width of 4 feet and an extreme length of 8 feet, so that an industrial truck can be operated wherever a hand truck can go, while the former will ascend grades impossible to the latter.

Fig. 21 shows a standard G.V. 2000-pound industrial truck, of which there are several hundred in use. Both the battery and the driving mechanism are suspended below the platform, which has rounded corners and is extended to protect the mechanism at every point. Its speed on hard level surfaces is 7 miles per hour; its average radius, 25 miles on one charge of the battery, the current consumption

for a full charge amounting to 6 to 8 kilowatt hours. For grades up to 10 per cent, only one motor is employed. When equipped with two motors, each rear wheel is driven by an individual motor geared to a housed spur gear fastened to the wheel. A spring-returned controller is used, the operating lever returning to neutral when released by the driver. The brake is also spring-operated and is normally set, so that in order to run the car the driver must keep the brake pedal depressed. A further safety precaution is an automatic cut-off

Fig. 21. G.V. One-Ton Industrial Truck Handling Freight

switch connected with the brake, so that in releasing the pedal of the latter the power is cut off automatically. In addition to this pedal, two operating handles are provided, one for the controller and the other for steering, the truck being capable of turning around in a 7-foot radius. In general freight-shifting service, the hauls averaging from 200 to 800 feet, each truck displaces from four to six men with hand trucks. The efficiency of these trucks is frequently increased by using them in connection with trailers and large numbers are employed in factories for transporting material from one department to another.

ELECTRIC TRUCKS

Classification. There is little, if any, difference in design between delivery wagons and trucks, the frames, axles, wheels, springs, and transmission simply being made heavier in proportion to the great increase in load to be carried, while there is a corresponding difference in the power of the motor or motors and in the size of the chains or other essentials of the transmission. As already mentioned, some makes, such as the Walker, adhere to the single-motor power plant even in sizes up to 2 and 3½ tons' capacity, and the G.V., Lansden, Waverly, and G.M.C., up to 5 and 6 tons, on the score of increased economy and higher efficiency, while others, such as the Commercial, employ two motors on vehicles as small as the 4000-pound size and four motors on larger trucks.

Next to the delivery wagon, in which electric power has scored a great success, trucks of 2-ton and 3-ton capacity are the most common forms of electric vehicles—though the 5-ton size has come into general use for brewery service—several hundred being run by brewers in New York, while one St. Louis company has nearly a hundred. Electric trucks of 6- and 7-ton capacity are also built. In order to obtain the increase in load-carrying capacity, the size of the motor must naturally be enlarged, with a corresponding increase in the power consumption, which calls for a very much larger battery. In order that the capacity of the battery may be sufficient to give the vehicle a practical radius of travel on a single charge without unduly adding to the weight, the speed is reduced, so that electric trucks of 2-ton capacity usually have an average speed of 8 to 10 miles an hour; 3-ton trucks, 6 to 9 miles an hour; while 5-ton trucks seldom exceed 7 miles an hour.

Characteristics of Chassis. The electrics listed by the General Vehicle Company afford an excellent example of a standard design of chassis applied to cars ranging from 1000 pounds up to 5 tons' capacity, the intermediate sizes being 2000 pounds, 2 tons, and 3½ tons. Naturally, the first two are delivery wagons and are capable of traveling 45 miles on a single charge of the battery at a maximum speed of 12 and 10 miles per hour, respectively. The 2-ton wagon, while capable of the same mileage, has a maximum speed of but 9 miles per hour. This is further reduced to 8 miles per hour for the 3½-ton truck, which has a radius of 40 miles on a charge, while the

5-ton truck travels only 7 miles an hour as a maximum and has an extreme radius of 35 miles on a charge. In every case, only a single

Fig. 22. Rear View of G.V. 4000-Pound Chassis

motor is used, and as the design in all other respects is also standard for all sizes, a description of the 4000-pound wagon will suffice.

Fig. 23. General Electric Motor

With the exception of the use of a single-motor drive, a large number of the parts employed are practically the same as those used

in other makes of electrics. The foundation of the entire car consists of a pressed-steel frame, to which are directly riveted the cradle for

Fig. 24. Rear Axle of G.V. 2-Ton Truck

carrying the battery, the spring hangers, and the supports for the countershaft bearings.

A view of the complete chassis will be found in Fig. 2. The view is taken from above and illustrates every essential except the battery. At the rear are the semi-elliptic springs, the solid-steel axle, artillery wheels with solid rubber tires and large driven sprockets, driving chains, the single motor suspended from a transverse tubular member on the frame, the enclosed silent-chain drive from the motor to the countershaft, the wiring in conduits from the controller to the motor, and the countershaft with its radius rods to equalize and maintain its distance from the rear axle. These rods also serve to

Fig. 25. Front Axle of G.V. 2-Ton Truck

take the stresses of driving off the rear springs. Just in front of the countershaft is the steel cradle for the battery trays; at the left, that is, at the front of the truck, is the steering gear, forward axle, springs, and wheels.

An excellent view of the entire bottom construction, which gives a clear idea of the arrangement of the power and the drive, is shown in Fig. 22, while the essentials comprising it are shown in detail in Figs. 23, 24, and 25. Fig. 23 is a G.E. multipolar, ironclad motor. Fig. 24 shows the rear axle, while the forward axle and its steering attachments are shown in Fig. 25. A 44-cell storage battery furnishes current at 85 volts, the motor being wound to operate economically at this voltage. The battery is in sectional form, in crates of such weight and size as to permit of easy removal or of replacement from either side of the vehicle. It is so arranged that it may be recharged without disturbing it; but, where two batteries are employed, a charged set may be easily and quickly substituted for the exhausted battery.

The controller is of the continuous-torque type which will permit of changing the motor speeds by degrees without interrupting the power between any of the steps. This gives a gradual and steady acceleration, without the jerk and strain so detrimental to the life and efficiency of every part of the vehicle. The motor is designed along the lines which have proved so successful in street-railway work. It has a very heavy shaft as well as a simple and durable brush rigging and is wound to show not only a high efficiency but also a high capacity for overload. The armature shaft, which is carried on annular ball bearings that tend to greatly increase the efficiency of the motor as a whole, is suspended on a transverse bar pivoted to the side members of the frame forward of the rear axle. This pivoted suspension keeps the motor shaft parallel with the countershaft throughout the entire range of chain adjustment and permits the use of an efficient silent-chain drive, which, as will be noticed in Fig. 2, is enclosed in an aluminum housing.

The countershaft is housed in and is carried on four taper-roller bearings inside the tube, the latter being held in self-aligning ball sleeves in hangers riveted to the sides of the frame. The two short driving shafts are connected by a spur differential and carry at their outer ends small sprockets for the roller chains to drive the rear wheels, the entire countershaft being a complete unit. It is driven by a silent chain of ample width running over a small pinion on the motor and over the gear of the differential. Altogether, this is a very efficient form of truck.

GASOLINE VEHICLES

GASOLINE DELIVERY WAGONS

Classification Limits. It will be found on a brief examination of the subject that this is a far more comprehensive heading than would appear at first sight, as it includes everything from the little three-wheeler up to the type known as the "light truck", but which is, in reality, also a delivery wagon with an open platform, or stake type of body. The range of carrying capacity is from one to two hundred

Fig. 26. Autocar Two-Cylinder Delivery Wagon

pounds up to one ton, or slightly more, as many delivery wagons and light trucks are built with a load capacity of 2500 pounds or even 3000 pounds.

Autocar. The Autocar delivery wagon, Fig. 26, affords an excellent example of a vehicle designed especially for the most severe business conditions. The motor is of the two-cylinder, horizontal, opposed, four-cycle type, the cylinder dimensions being $4\frac{3}{4}$-inch bore by $4\frac{1}{2}$-inch stroke, and is rated at 18 horsepower. The crankshaft is mounted on imported annular ball bearings, which not only add greatly to the efficiency of the motor as a whole, but do away with the attention necessary to adjust plain bearings. This construction,

which is far more expensive than plain bearings, also reduces the number of parts which are subject to damage should the driver neglect to provide sufficient oil. The lubrication system is entirely automatic in operation. Two flywheels are carried on the crankshaft, the forward one having its blades cast staggered so as to set up a strong current of air, thus eliminating the necessity of a belt- or gear-driven fan, while the rear flywheel carries the clutch. The importance of providing ample weight in the balance wheel is something to which insufficient attention has been devoted in the past, its influence upon the starting ability and the smooth-running qualities of the vehicle being extremely marked, especially where a two-cylinder motor is employed. Both flywheels on the Autocar motor are counter-weighted, and this, supplemented by a careful balance of all the reciprocating parts, makes an extremely smooth- and quiet-running motor with unusual starting and grade-climbing ability for its size.

The crankcase is split horizontally into two sections, the lower half carrying the cylinders, crankshaft, camshaft, and water pump, while the upper half carries the push-rod guides, the magneto, the oiler, and a gear for driving the water pump. The magneto and oiler are both driven through bevel gears and short shafts, reducing the possibility of failure in these two highly important essentials—ignition and lubrication—to a minimum. The upper section of the crankcase is readily removable, carrying its parts with it and thus giving access to the crankpin bearings without the necessity of dismantling the motor. A Bosch magneto with a fixed firing point is employed, thus taking this element of control out of the hands of the driver. Lubrication is by a force-feed oiler delivering oil through a sight feed to the crankcase, from which the pistons, crankpins, and main bearings are lubricated by splash. Both the magneto and the lubricator are simply attached to the crankcase by wing nuts so that they may be removed without the aid of tools. A hydraulic speed regulator, connected in the circulation circuit of the cooling water, controls a throttle placed in the intake manifold between the carburetor and the cylinders, limiting the speed of the motor to 1400 r.p.m. and that of the vehicle to 18 to 20 miles per hour.

A patented floating-ring clutch, which has been developed on the same make of pleasure cars and used for a number of years, constitutes the first step in the transmission. It consists of a bronze floating

ring, lined with cork inserts on its inner face, and is mounted on four keys on the inside of the rim of the rear flywheel, thus rotating with the latter. Two cast-iron rings, adapted to clamp the bronze ring when the clutch is engaged, are mounted on the clutchshaft which extends into the transmission case. Engagement is accomplished by a sliding trunnion and four-toggle links, the motion of which is checked by a dashpot and a plunger. This insures gradual automatic action, entirely free from jerk, regardless of the care exercised by the driver. The addition of small springs to the floating ring eliminates all noise, whether the clutch be engaged or not.

Fig. 27. Autocar Double-Reduction Floating Rear Axle

Fig. 28. Rear View of Autocar Delivery Wagon

The transmission housing is all in one piece, except its cover plate, and has been so designed that all the shafts and gears may be removed without disturbing the housing itself. The shafts are large and are

Fig. 29. Autocar Engine and Transmission Mounted on Separate Sub-Frame

carried on adjustable roller bearings, while the gears have broad faces and heavy teeth. Three speeds forward and one reverse, operating progressively, are provided, lubrication being obtained by covering the shafts and gears with a bath of semi-fluid oil.

Fig. 30. Autocar Engine and Transmission—Plan View

Both front and rear axles have been designed especially to meet the requirements of the heavy service imposed upon them in carrying the load on solid rubber tires. The front axle is of the tubular type,

with extra heavy yokes for the steering spindles, which are made integral with the spring saddles. Adjustable roller bearings are employed in the wheel hubs. The rear axle is of the full floating type, with a double-gear reduction. A bevel pinion at the end of the propeller shaft meshes with a large bevel gear on a short transverse shaft, from which the drive is transmitted to the differential case by means of a pair of substantial spur gears, the method of mounting them being shown by Fig. 27. The complete axle, as well as the spring suspension, the brakes, and other details are shown in the rear view, Fig. 28.

One of the chief features of advantage on the Autocar delivery wagon is the mounting of the complete motor and transmission, barring the rear axle, on an independent sub-frame, as shown in Figs.

Fig. 31. Plan View of White Delivery Wagon Chassis

29 and 30. An illustration of the complete chassis would show every part of the power plant to be accessible by lifting the bonnet, while the complete unit, as shown separately, may be removed from the chassis and replaced by another. The rear view of the chassis, Fig. 28, shows the relative location of all the essential parts, including the gasoline tank, which is placed transversely on the main frame directly under the driver's seat. The frame is of pressed steel, perfectly rectangular and heavily reinforced. Two sets of brakes act on drums attached to the driving wheels, while the suspension consists of double-elliptic springs in the rear and semi-elliptic springs placed forward directly under the motor.

White. This may be regarded as a representative standard design, as will be evident from the photo of the chassis, Fig. 31, show-

ing that it differs from heavier-capacity vehicles of the same make only in being shaft-driven and having lighter dimensions. It is built in 1500- and 3000-pound sizes, the chassis illustrated being of the latter capacity. Single rear tires are usually fitted on the smaller car, and pneumatics are frequently employed to take advantage of the higher speed thus made possible, an example of this practice being illustrated by Fig. 32. Apart from the difference in dimensions and tire equipment, both sizes are the same, each being equipped with a $3\frac{3}{4}$- by $5\frac{1}{2}$-inch motor, the cylinders of which are cast in one piece,

Fig. 32. White Delivery Wagon with Light Top Body and Pneumatic Tires

with the intake and exhaust passages integral. This motor is rated at 30 horsepower and fitted with a compression release for starting. A single-nozzle water-jacketed carburetor supplied with hot air from a jacket on the exhaust pipe, a high-tension magneto for ignition, and a gear-driven centrifugal water pump comprise its auxiliaries.

GASOLINE TRUCKS

Load Efficiency Increases with Size. It will be apparent that above the 2-ton size the load efficiency increases, as, once a certain point is reached, additions to the weight caused by increasing the dimensions of the load-carrying space and adding to the power of the motor are disproportionately small as compared with the increase in

load capacity. For example, one truck of 3-ton capacity has a chassis weighing only 4500 pounds, which tips the scales at 5200 pounds completely fitted, or "all on"; on the other hand, another chassis for the same nominal carrying capacity, i.e., 3 tons, weighs 6000 pounds. However, as no standard for rating the load-carrying capacity of gasoline trucks has ever been attempted, and one maker's 5-ton truck is sometimes no larger than the 3-ton truck of another, it is often difficult to make comparisons that will be fair on a basis of catalogue weights alone.

MOTOR DETAILS

Design

Both the design and construction of internal-combustion motors for commercial use are along lines similar to those employed on pleasure automobiles except as modified by the requirements of the more severe service. This necessitates a higher factor of safety throughout, such as increased provision for lubrication and cooling; extra large bearing surfaces, which must be readily accessible for adjustment, except, of course, where antifriction bearings are employed; increased crankshaft dimensions; broad gear faces; and a considerably increased weight of flywheel in order that the motor may develop as high a torque as possible at low speeds. The greater amount of weight in the rim of the flywheel also eliminates motor vibration to a considerable extent and makes the engine run much more smoothly. Such variations of design as are usual in the pleasure-car motors are to be found in the commercial type; in fact, where a manufacturer builds both types, the same lines are followed in each case, the only practical difference being in the dimensions and speeds. It will be necessary, accordingly, to refer to only a few of the more representative makes.

Long Stroke, Low Speed. Generally speaking, a commercial motor is of the long-stroke low-speed type, some idea of the proportions being obtainable by the dimensions of the White and the Pierce-Arrow motors for 5-ton trucks. The former has a $4\frac{1}{4}$-inch bore by a $6\frac{3}{4}$-inch stroke, while the latter measures $4\frac{7}{8}$ by 6 inches. Similar small variations in dimensions are to be noted in practically every make, in conformity with the varying standards of compression and volumetric requirements adopted by their designers. This will

be apparent by a comparison of a few makes, such as the Locomobile, 5 by 6 inches; G.V. and Mercedes, 4.25 by 5.9 inches; Peerless and Kelly, $4\frac{1}{2}$ by $6\frac{1}{2}$ inches; Vulcan, $4\frac{3}{4}$ by $5\frac{1}{2}$ inches. No increase is made in motor dimensions above the 5-ton size, the extra carrying capacity being gained by higher gear reductions and lower speeds, the Vulcan motor mentioned being employed on both the 5- and 7-ton sizes of that make. These motors are variously rated at 35 to 40 horsepower,

Fig. 33. Peerless 5-Ton Motor, T-Head Type

viz, Vulcan, 36 horsepower; White, 40; Kelly, 38.5; Peerless, 32.4; Pierce-Arrow, 38.

Causes of Variations in Ratings. The variation in the ratings is due to a number of causes, although one of the chief reasons is the differences in the practice followed, i.e., in some cases, the power stated is the maximum indicated horsepower based on the dimensions and worked out by the S.A.E. formula of $\frac{D \times N}{2.5}$, in which D is the bore, N the number of cylinders, and 2.5 an arbitrary constant derived from taking the speed characteristics of a large number of motors and striking an average representing a piston speed of 1000 feet per minute. In other cases, it is the result of actual brake tests

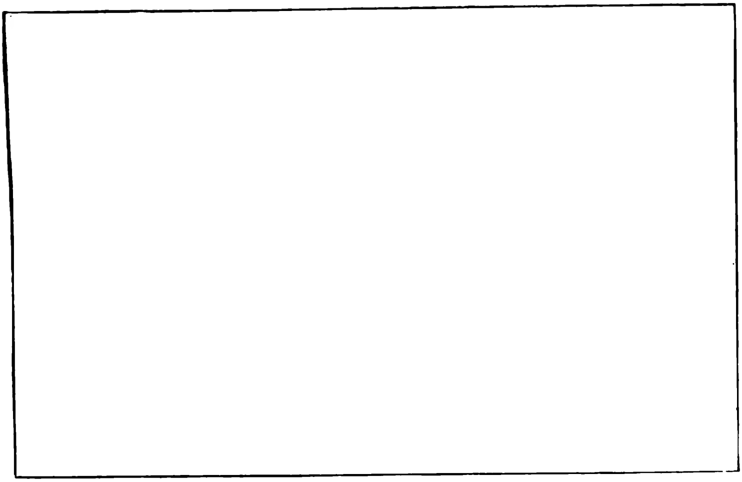

Fig. 34. White 40-Horsepower Block-Type Motor for 5-Ton Truck

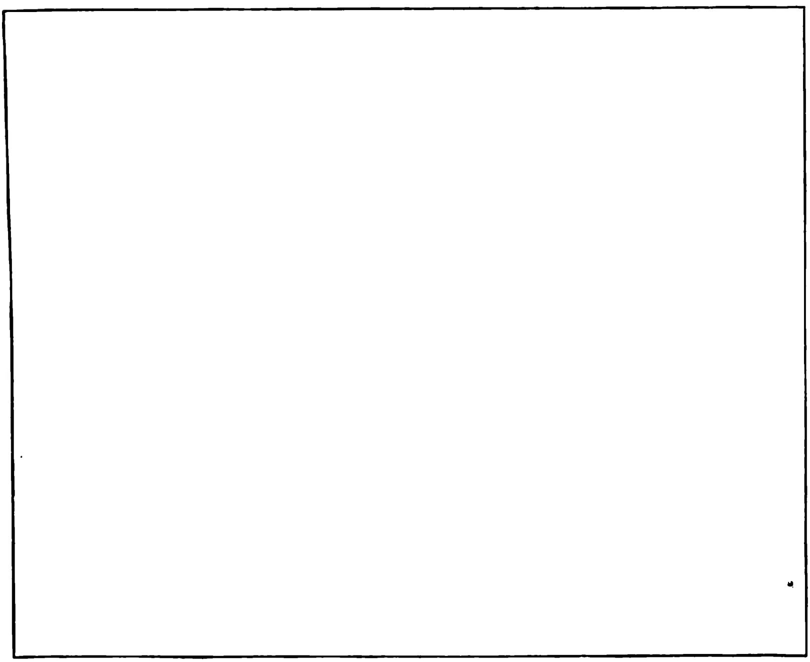

Fig. 35. Pierce-Arrow Motor for 5-Ton Truck

and is accordingly based on the maximum r.p.m. rate of the motor: while in still others it is the power which the motor is capable of developing at the speed at which it is controlled by the governor, usually 800 to 1000 r.p.m., to give the best service from the truck of the capacity for which it is designed. For instance, the rating of the Kelly motor is based on a speed of 900 r.p.m., while that of the Peerless, Fig. 33, of the same dimensions, is its indicated horsepower figured according to the above formula. The White motor, Fig. 34, is an example of the L-head type; while the Pierce-Arrow, Fig. 35, like the Peerless already mentioned, is of the T-head type.

Accessories

Ignition. In every department of commercial-car practice, the designer aims to make the operation of the machine as nearly automatic as possible and to that extent to relieve the driver of any opportunity to exercise his discretion. The usual practice is to employ a magneto fitted with an automatic spark-timing device. This operates on the principle of the centrifugal governor and is controlled entirely by the speed of the motor, so that when the motor is stopped the spark timing is fully retarded and there is no danger from a "back-kick" as is the case where this precaution is inadvertently overlooked. As the motor speed increases, the occurrence of the spark in the cylinders is automatically advanced to correspond, thus relieving the driver of this important function and preventing the abuse of the motor in unskilled hands. The same slight differences in detail as found on the pleasure type are also found in the ignition systems of commercial cars.

Carburetors. Carburetors also are the same both in principle and construction as on the pleasure cars, except in instances where they have been specially designed for commercial service, in which case the modification applies to the construction. In view of the very general custom in this country of leaving the design of auxiliaries to the accessory manufacturer, the number of these instances is very small, so that in the majority of cases the carburetor manufacturer sells the same carburetor for either type of vehicle. To permit of the efficient utilization of lower-grade fuels, ample provision is usually made for heating the carburetor by a large warm-water jacket and a supply of hot air taken from a collector located on the exhaust pipe.

Cooling Systems. The so-called direct system, in which air is relied upon to keep the cylinder walls of the motor at a temperature that will permit of efficient operation without danger of seizing, was never attempted on commercial vehicles except in the lighter sizes. Most of these were light delivery wagons, although one make of 3-ton trucks employed a blower system for several years. However, air as the cooling agent without an intermediary in the form of a water circulation has been definitely abandoned on the commercial car. Both the principles and the operation are the same as on pleasure cars, due allowance being made for the more severe service by increasing the size of the pump, the section of the cylinder jackets, the area of radiating surface, and the diameter of the connections.

Radiator Construction. The radiator is the most vulnerable part of the truck, and precautions are therefore taken to protect it from injury. In order to be proof against the constant vibration and jolting, the gilled-tube type of radiator is employed in the majority of instances. Accidental damage is usually provided against by extending the frame and equipping it with a bumper, and further protection is sometimes afforded by mounting a heavy wire screen in front of it. This is done more frequently on honeycomb, or cellular, radiators, as they are liable to suffer severely when prodded with the steel-shod pole of a horse-drawn truck, and are difficult and expensive to repair. In the case of the gilled-tube type, only those tubes actually struck are likely to be damaged and they will frequently bend without rupture, while often nothing more serious happens than the bending and derangement of the cooling fins with which each tube is surrounded. These tubes are placed vertically and, in the case of the Reo 2-ton truck radiator, Fig. 36, are made demountable, so that a damaged tube may be easily replaced in a short time without the necessity for making any soldered repairs. It will be noted that each pair of tubes is held in place by a bolted yoke, so that upon loosening the yoke they may be lifted out. This illustration also clearly shows the flat copper tubes, which are placed with their narrow edges facing the air current, as well as the copper radiating fins attached to them. The upper and lower parts of the radiator are hollow castings, which form tanks, the sides merely providing a support and spacer for the tubes. The usual construction consists of a removable tank, which forms the top and bottom

chambers, with a bank of gilled tubes having their ends expanded and soldered into perforated plates, the solder playing an unimportant part, as such joints cannot be relied upon where there is much vibration.

Unless properly provided against, one of the chief sources of injury to the radiator arises out of the twisting of the frame under torsional stresses. Flexible joints between the radiator and motor are accordingly necessary to take care of relative movement, and it is common practice, both in this country and abroad, to employ rubber hose for this purpose. By reason of the heavy loads carried and the use of solid tires, this precaution is not sufficient to guard the radiator against the effects of vibration and road shocks, so that it is usually mounted on some kind of spring suspension. This spring suspension usually consists of a pair of helical springs, one on either side, so that the radiator has no solid connection with its support. In some instances, the radiator is hung on a pair of trunnions, similar to a gun mounting, but this form, while providing ample allowance for movement, does not cushion it against shocks. Still another method consists in mounting the radiator on an extension of the motor, the motor itself being carried on a three-point support, so that the radiator and motor move together; but, unless provided with some form of spring buffer between them, this type suffers from the same disadvantage as the one just mentioned. Figs. 37 and 38 show some typical methods of radiator protection.

Fig. 36. Reo Demountable-Section Gilled-Tube Radiator

Fans. In every case, the radiator is supplemented by a fan driven at high speed, and, in view of the slow travel of the heavier trucks, the proper working of the cooling system depends upon the

efficiency of the fan, since the speed of the vehicle cannot force a strong draft of air through the radiator as it does in a touring car. Thus, the fan is a very important part of the cooling system on a slow-moving vehicle, as it must provide an ample draft, no matter how low the road speed may be, otherwise the engine is liable to heat beyond the point where the oil begins to lose its lubricating qualities. An inefficient fan allows excessive heating every time it is necessary to climb a long hill.

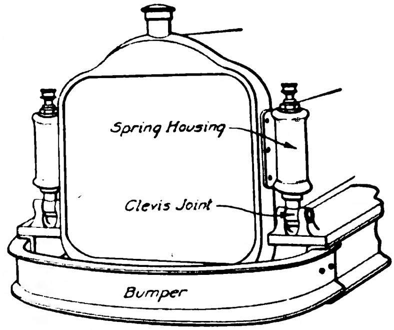

Fig. 37. White Radiator Mounting, Providing Spring Cushioning and Relative Movement through Clevises

Circulating Apparatus. In the majority of cases, the cooling water is circulated by a pump on commercial-car motors, though many heavy trucks, such as the Kelly-Springfield, have thermosiphon circulation. This pump is of the centrifugal type and is capable of delivering a much greater volume of water than are those employed on pleasure-car motors of corresponding power, owing to the reduced road speeds of trucks. These pumps vary more or less in design, but are based almost without exception on the centrifugal principle, as the latter is the only one which will permit of a thermosiphon circulation through it in case the impeller ceases to revolve. A stoppage of the gear type of pump also stops the circulation at once.

Lubrication. Granting that an excess can be prevented from reaching the combustion chambers of the cylinders, it is axiomatic that the power plant of a motor truck cannot have too much oil. In commercial service, the demands upon the lubricating system are quite as severe as they are upon the cooling system, and the failure of one usually involves the failure of the other in a short time. Hence, a greater amount of oil must be provided and every precaution taken to insure its reaching the bearings. Except for the increase in the quantity of

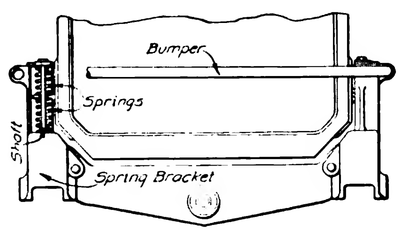

Fig. 38. Spring Hangers Combined with Front Hanger Bracket

lubricant, this does not differ in any way from the requirements of the pleasure car. Consequently, the systems employed are practically the same in both cases. The White lubrication system shown in Fig. 39 illustrates a typical sight-feed system.

Motor Governors

Of the two chief evils that beset the motor truck in the hands of the untrained driver—speeding and overloading—the former is the more destructive, as the driver who will overload his truck will also run at excessive speeds, and, with a heavy load, this is severe punishment for the entire mechanism. The practice became so common in the early days of the motor truck—nearly all drivers

Fig. 39. Sight-Feed (Drop) Lubricating System as Used on White Trucks

then being graduates from the pleasure-car field—that it has now become customary to govern the speed of the motor. The governor itself is usually sealed to prevent its being tampered with by the driver.

General Characteristics. The most generally accepted type is that of the usual centrifugal governor attached directly to the motor and operating a butterfly valve in the intake manifold between the regular carburetor throttle and the valve ports. Owing to the high motor speeds and the slight amount of movement necessary, the governor is very small and compact, so that it will frequently be found incorporated in the crankcase at the end of the camshaft. A variation from this is a drive taken from an outside auxiliary, such as the magneto shaft or water-pump shaft. In either case, the speed of the

governor is always directly proportional to that of the motor itself and bears no relation to that of the vehicle. This is a disadvantage at times, as in pulling through a heavy road on low speed when the maximum power of which the motor is capable is required.

Controlling Car Speed. An improvement on this practice has been the adoption of a vehicle "speed controller" which, while acting on the motor itself in the same manner as the usual motor governor, is controlled directly by the speed of the car and bears no relation to that of the engine. With this type, the motor is free to run at any speed at which the hand-operated throttle will supply it with fuel, so long as the speed of travel does not exceed that for which the governor, or controller, is set. So far as the motor is concerned, it is not directly governed and may be speeded up to any extent necessary to pull the car through heavy going or out of a ditch, as the controller does not come into action while the car is moving slowly. Practically, the only disadvantage of this type is the fact that it does not prevent the motor from racing, as does the former, when the load is suddenly removed, with the throttle open. The vehicle speed controller is driven either from one of the front wheels or from a shaft of the transmission, as its operation depends entirely upon the speed of the car. In addition to the centrifugal method of speed control, the hydraulic principle is also employed. It will be apparent that as the motor speed increases the circulation of the water, as driven by the pump, does likewise, and there is a corresponding rise in pressure in the cooling circulation. This rise in pressure is utilized to act on a large diaphragm connected with a plunger attached to a butterfly valve. A description of some of the governors in use will make clear the method of taking advantage of the different principles of operation.

Centrifugal Type. In Fig. 40 is illustrated a typical centrifugal governor designed for attachment to one of the auxiliary shafts, as will be noted by the driving gears at the bottom. As the revolving weights tend to spread against the compression of the helical spring surrounding the spindle on which they revolve, they push up a yoke to which a shaft directly connected with the throttle valve is attached. As in the case of the steam engine, this valve is entirely independent of the hand-operated valve which may thus be left all the way open. The details of construction of the Pierce governor are shown by

the sectional view, Fig. 41, in which the weights are at the right. As the triangular weights open under the centrifugal force generated, they push the rod forward, and, as this rod has a rack cut on it

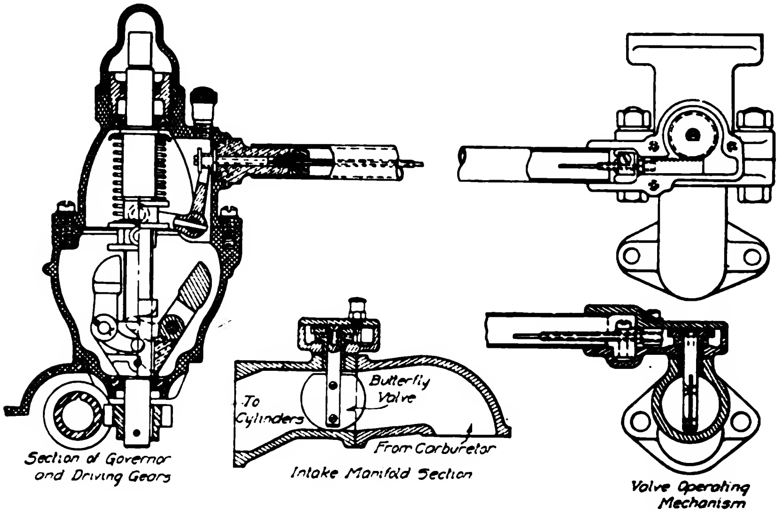

Fig. 40. Sectional Diagrams of Centrifugal Type of Governor

that meshes with a pinion on the butterfly valve, this action tends to close the valve. A spring keeps this rod pressed against the spindle on which the weights are mounted, but is not connected with the spindle in any way. As is true of all governors in this service,

Fig. 41. Sectional View of Pierce Centrifugal Motor Governor

a speed adjustment and a method of sealing it against tampering are provided.

Hydraulic Type. An example of the hydraulic type of governor is shown in section in Fig. 42, while the application of this form of governor is illustrated by the Reo 2-ton truck motor, Fig. 43. As

will be seen in the section, this type consists of a water chamber, diaphragm, spring, and operating lever; the operating mechanism

Fig. 42. Hydraulic Type of Governor

being combined with the governor proper results in a simple and compact unit which requires only one connection. This connection is led from the circulating system on the cold-water side, as will be noted in Fig. 43, in order to bring it close to the pump. As the speed of the pump increases, the pressure increases, and the diaphragm is forced down against the spring, carrying with it the lever operating the valve

Fig. 43. Hydraulic Governor as Installed on Reo 2-Ton Truck Motor

through a rack and a pinion. As the pressure decreases, the spring returns the diaphragm, and with it the valve, to its normal position. The water chamber, operating-lever housing, and the spring-retaining plug are sealed so that the adjustment cannot be varied without disturbing one of these seals. In this, as well as in the centrifugal type where the adjustment is effected by altering the tension of a spring, it will be obvious that the spring could readily be screwed up so tightly that no speed of which the motor was capable would have any effect on the governor, thus practically cutting out its action altogether.

POWER TRANSMISSION DETAILS

Clutch and Transmission

Clutches. *Cone Type.* A comparison of the specifications of a number of representative makes of trucks reveals a variation in clutch design about equivalent to what would be found on an equal number of pleasure cars, except that a greater number of instances of the leather-faced cone occur in the trucks. This is the oldest type employed on the automobile and is likewise the simplest in construction, which probably accounts for its more general retention in the commercial field. What is termed the *direct* conical type, in which the leather-faced cone engages by moving forward into the corresponding wedge-shaped recess of the flywheel, is in more general use than the *indirect*, or *internal*, cone in which the male member moves backward into engagement. An example of the latter type is found on the Peerless trucks, while the Garford, Kelly, Vulcan, Mais, and Pierce are representative of the former. In the case of the Pierce, the cone operates in an oil bath, the others running dry, as is more often the case.

Multiple-Disc Type. The Packard and Autocar in this country and the De Dion in France have long been fitted with a three-plate type, the Albion (British) having a single-plate form of clutch in the heavier sizes. Multiple-disc clutches are found on the Locomobile, the Mack, and the Reo, and other American makes.

Transmission. Owing to the great reduction in speed necessary between the motor and the driving wheels, transmission plays a more important part on the commercial vehicle than it does on the pleasure car. On the latter, its services can be dispensed with in an

emergency, as the car can be started on the direct drive in case of accident to the intermediate speeds, but this would manifestly be impossible on a heavily loaded truck. In this connection, it is to be noted that the term "transmission" has come to signify the "change-speed gearset" alone, doubtless owing to the awkwardness of the latter appellation, and does not apply to the transmission of the power from the motor to the rear or front wheels or to all four, as the case may be.

Sliding-Gear Type. In the majority of instances, the sliding-gear type of transmission is employed for commercial work, in which the gears are actually slid into engagement with each other to effect the various ratios of driving and driven members. This type is

Fig. 44. Type of Transmission Employed on White Shaft-Driven Trucks

practically universal on the pleasure car, so that only a brief reference to it is necessary here. On almost all except the lighter vehicles, it provides four forward speeds, the others having but three speeds and reverse. Fig. 44 shows the White transmission as employed with a shaft drive. Owing to the controlling connections being absent, this has been inadvertently photographed with both the first, or lowest speed, and the direct, or highest speed, engaged. The large gear at the left, shown in engagement with its corresponding gear on the layshaft, gives the first speed. By moving it forward until the gear just ahead, with which it is integral, meshes with the next gear to the right on the layshaft, the second speed is obtained. Moving the single gear at the right back until it meshes with the right-hand gear of the pair on the layshaft gives third speed. For fourth speed,

or direct drive, this same gear is moved forward, its forward face being cut in the form of a dog clutch that engages a similar gear permanently attached to the clutchshaft. This is unusual, as the dog clutch is generally formed of a smaller diameter extension on the hub of the direct-drive gear. The two gears at the extreme right-hand end are permanently engaged and serve to drive the layshaft. By moving the largest gear to the extreme left, the reverse is engaged, this being effected through an intermediate pinion, or idler, part of which is just visible below the main shaft at that point. The moving members slide on splines cut on the main shaft, the sliding being sometimes effected by making the main shaft of square section.

Fig. 45. Peerless Transmission and Countershaft

A similar transmission, combined with a bevel drive and spur-gear differential on a jackshaft for side-chain final drive, is that of the Peerless, Fig. 45. This is shown engaged on the direct drive, so the dog clutch is not visible. The material used in the housing is usually aluminum, sometimes cast iron, and, in the case of the Locomobile, manganese bronze. Annular ball bearings are employed in many instances, the bearings themselves being apparent in the White transmission and their mountings in the Peerless. Taper roller bearings are also employed for the same purpose. Operation is almost invariably by the selective method, the gear lever being shifted across through a gate to pick up one or the other of the sliding members shown. The control lever of the White, which is mounted directly on the transmission housing, is shown in Fig. 46. This lever is more often mounted at the side in a fixture also carry-

ing the emergency-brake lever, as on the Pierce. On this truck, only three forward speeds are provided.

Mack Transmission. The Mack transmission, Fig. 47, is a selectively operated type in which the gears of the various speeds are always in mesh, small clutches being designed to slide in either direction on the squared main shaft, engaging the particular speed desired. These clutches are practically small gears which mesh

Fig. 46. Completely Assembled White Transmission, Showing Control Lever

with internal-gear members attached to the driving members. They will be noted lying between the driving gears on the main shaft, in the illustration. The gear housing in this case is of phosphor bronze.

Use of "Dog" Clutches. A variation of the Mack type of transmission employs what are known as "dog" clutches, probably from the fact that they apparently *bite* into one another, being cut with a comparatively small number of heavy teeth on their end faces. These teeth, if they can be properly so-called, are of heavy section

and are cut with an easy angle which insures ready engagement. This will be noted in the direct-drive engagement of the White gearset. The dog-clutch type of gearset has been employed more in Great Britain than in this country. Its great advantages are that the driving gears are constantly in mesh and that the dog clutches can be engaged without particular attention being paid to the speed at which the two shafts are revolving, as is necessary with the sliding-gear type. The details of a transmission of this kind, as well as

Fig. 47. Mack Transmission Used on Manhattan Trucks

of the method of operation, are clearly shown in Fig. 48, which is a Cotta transmission designed for use on worm-driven trucks. As shown in the illustration, the first, or low, speed is engaged, the clutch on the layshaft at the lower right-hand corner being in mesh with its counterpart on the large, or low-speed, gear. The clutch-shaft being at the right-hand end of the gear box, as shown, the drive is then through the pinion on it, the large gear below, with which it is in mesh, and then through the layshaft and the pair of gears at the left-hand end, these gears being fastened to their respective

shafts. The other gears, with the exception of the clutchshaft pinion previously mentioned, are free to rotate on their shafts and are permanently in mesh. However, the male members of the individual clutches, while free to slide on the shafts, must turn with them, so that when engaged they "pick up" the various gears corresponding to the different speeds.

Silent-Chain Transmission. Another form of transmission, which has been used to a greater or less extent abroad, but which has found little favor here, is the silent-chain type. This is along similar lines to the Mack transmission illustrated, except that roller chains take the place of the permanently meshed gears, dog clutches being engaged to pick up the latter according to the speed desired.

Final Drive

Until a few years ago, there was a sharp line of demarcation between the pleasure car and the commercial vehicle where the

Fig. 48. Cotta Individual (Dog) Clutch Transmission Designed for Worm-Driven Trucks

important final drive was concerned. Practically all pleasure cars were shaft-driven, and, to the same extent, commercial cars were chain-driven. The tendency that has manifested itself in the interim makes it apparent that the history made in the development of the pleasure car is apt to repeat itself in commercial-car development. In other words, chain-driven trucks were largely in the majority a few years ago, but the recent advances made in live-axle construction have had a marked effect and their adoption has now reached such a scale that, barring something unforeseen, the chain on the truck will soon disappear as it has from the touring car.

Classification. As at present employed, there are four general classes of final drive on commercial cars. In the order of their age and present comparative importance, these are: first, the double side-chain from a centrally located countershaft carrying the differential and the bevel drive, and usually combined with the gearset, or transmission, so called; second, the worm drive, which differs from the bevel-gear type only by the substitution of a worm and a worm wheel for the bevel gear and the pinion; third, the double-reduction live axle, in which a bevel-gear drive is employed in connection with a second reduction in speed through the spur gears; fourth, the so-called internal-drive rear axle, in which the first reduction is through the conventional bevel gear and the second is by means of a small spur pinion meshing with an internal gear cut on the inner face of a drum attached to the driving wheel. It may occasion some surprise to note in this connection that the worm drive is mentioned as being second in point of seniority, and further that no mention is made of the standard bevel-gear live axle. In the first place, the use of the worm on automobiles dates back to its employment on the Lanchester pleasure cars in 1898 and its adoption on the Dennis busses in London in 1903, on which it has been regularly used ever since. No mention is made of the standard bevel-gear axle here, since the latter is only adapted for use on light cars. The higher speeds at which these vehicles run do not necessitate the employment of extremely high reduction ratios, so that a live axle of this type may be employed without having to make the bevel gear of a size that would seriously reduce road clearance, on the one hand; or a bevel pinion that would exceed the mechanical limitations of this form of drive, on the other. It is rarely employed, however, on vehicles of more than $1\frac{1}{2}$ tons' capacity, and the ease with which the entire speed reduction necessary may be carried out in a single step by means of a worm gear will doubtless make the straight bevel type obsolete on commercial vehicles within the next few years.

Side-Chain Drive. Until the introduction in this country, at a comparatively recent date, of the worm drive, some form of double-reduction gearing has been used on all heavy motor trucks. The form most commonly used has been the double side-chain final drive, in which the primary gear reduction is obtained by means of a bevel gear driving the jackshaft and a secondary reduction in the chains

and sprockets. This type of drive, utilizing roller chains, has been used on nearly all heavy motor trucks since the inception of the commercial vehicle. With but one or two exceptions, on all these trucks of American manufacture no attempt has been made to house the chains in, and they run exposed to dirt, mud, and water.

Standard Types. A typical American side-chain drive for trucks of medium capacity is shown in Fig. 49, which illustrates a Timken unit. Except for the provision of brakes and sprockets at its outer ends instead of wheels, the countershaft, or jackshaft, is practically

Fig. 49. Timken Standard Jackshaft for Side-Chain Drive

a bevel-gear live axle. The rear axle is what is known as a "dead" axle in that it has no moving parts other than the wheels which revolve on bearings mounted on it. The two wheels are kept at a predetermined distance apart, and their parallelism is preserved by two distance, or radius, rods. A little consideration will make it plain that the thrust of repulsion against the ground of the driving wheels must be taken up on the vehicle before the latter can move, otherwise the rear axle would tend to travel forward independently until checked by the springs, which would then take the driving effort.

This is frequently done on pleasure cars, and makes a flexible power transmission which is easy on the mechansim and the tires, but which is not practical with the heavy loads handled on trucks. Hence, the radius rods are employed to transmit this strain to the frame of the car, but, at the same time, they must provide for a certain amount of relative movement in both a vertical as well as a horizontal plane, besides affording a certain amount of flexibility.

Radius and Torque Rods. Fig. 50, which represents a well-worked-out radius-rod design, illustrates how these various requirements are met. Starting at the right-hand end of the rod which is attached to the rear axle, it will be seen that this design consists of a connecting-rod type of bearing that permits movement in a vertical plane, as this bearing is held on a tubular section of the axle and

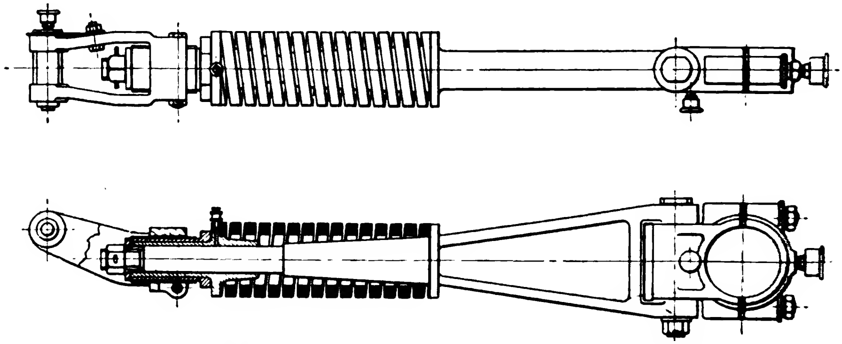

Fig. 50. Flexible Universally Jointed Radius Rod for Double Side-Chain Drive

is kept well lubricated. Just forward of the bearing is a heavy spindle which pivots the rest of the rod on the rear bearing, so that ample provision is made for lateral movement. The rod proper is in two parts held together by the compression of a heavy helical spring, which relieves the mechanism and tires of the initial thrust of starting, and also prevents shocks to the rear axle reaching the frame via the radius rod. Further provision for movement in a vertical plane is made by the attachment of the forward end of the rod to the frame, which forms a pivoted yoke. The threaded portion and the locked collar, noticed at the forward end, allow for adjustment in the length of the rod, this adjustment being provided for in the spring rod by the nut shown inside the yoke at the forward end. On shaft-driven cars, a torque rod is employed to take this thrust and also to take up the twisting effort, or "torque," of the propeller shaft.

Speed Reduction. The rear axle proper is simply a drop forging of I-beam section representing the strongest and lightest cross-section for a beam. It is forged integral with the pads, or saddles, for attaching the springs and is machined to receive the wheel bearings and the bearings of the radius rods which complete its construction. The driving sprockets are bolted to the pressed-steel or cast-steel brake drums and the latter are in turn bolted to the wood artillery wheels. On trucks of two to seven tons' capacity, the speed reduction between the motor and the rear wheels ranges all the way from 7 to 1 to 14 or 15 to 1. The first step in the reduction is carried out in

Fig. 51. Rear of Packard 5-Ton Chassis, Showing Size of Driving Sprockets

the bevel-gear drive of the countershaft and rarely exceeds 4 or 5 to 1, as the use of a larger bevel would involve the use of a cumbersome and weighty housing. The remaining reduction is accomplished by the difference in the driving and driven sprockets. How great this second reduction may be can be seen from Fig. 51, which is a rear view of a standard design of side-chain-driven heavy truck, the Packard. A study of this illustration will make clear several of the details of axle, spring, brake, and radius-rod construction described in previous paragraphs.

Worm Drive. The worm gear was tried tentatively on steam traction engines in England as early as 1850, but it was not until

1898, when it was applied to the driving of the Lanchester car, that it was seriously taken up for this purpose. The Lanchester worm is a peculiar variation of the more familiar Hindley type and is placed under the wheel to insure lubrication. An illustration of this worm gear will be found in the section devoted to the transmission of electric pleasure vehicles, as worm gears of this type are imported from England for use on the Detroit electric cars. The first rear-axle motor-truck drive of the worm type was a 3½-ton Dennis bus

Fig. 52. Phantom View of Pierce Worm-Driven Rear Axle

and quite a number of worm-driven Dennis busses have been in service in London for several years. Dennis was also the first to running in London. This was first put in service in 1903 and, though its introduction met with considerable opposition, it proved a success, mount the worm over the wheel, producing the so-called "overhead" type, which feature also came in for much criticism owing to its alleged failure to provide lubrication. It will be perfectly obvious that with the worm-wheel housing only partly full of oil this criticism would be unfounded, as the wheel acts as an excellent conveyor to carry the oil up to the worm. Eight years' use in London without failure of lubrication bears out this statement.

Development. The London General Omnibus Company was the first to design and manufacture on a large scale a new type of worm-gear axle in which the worm gear was mounted on a separate assembly. This design has superseded others until now, with some modification, it is accepted practice. The worm and the wheel are mounted in a very rigid block and, with their bearings, housings, etc., form a complete unenclosed transmission unit, as seen in Fig. 52, which is a phantom view of the worm gear employed on the

Fig. 53. Chassis of Pierce 5-Ton Worm-Driven Truck

Pierce trucks, the makers of the latter having been the pioneers in introducing this type into the United States. This unit is dropped into the bowl-shaped rear-axle housing and bolted in place. This mounting lends itself readily to accurate machining, every part being open and easily accessible. This is also true of the unit as a whole where inspection, adjustment, and repair are concerned. This housing is of heavy construction and, as it is rigid, prevents road shocks or stresses, other than those coming through the driving

axles, from disturbing the alignment of the worm gear. The housings of the driving shafts, or axles, are tubular, and the shafts themselves are assembled through the tubes into the squared sockets in the differential. This makes a very accessible assembly as, by pulling out the driving axles and disconnecting the universal joint, the worm unit can be lifted out of its housing. The socket, with several keyways in it extending forward from the worm proper, is for the reception of the splined end of the propeller shaft from the gearset. This keyed socket is the slip end of the rear universal joint in the shaft line and is designed to prevent relative movement of rear axle and of gear set from imposing excessive stresses on the propeller shaft.

The driving thrust and the torque are taken on a short heavy torque rod, which will be noted extending forward from the rear-axle housing just below the universal joint. This is a heavy drop forging and, as will be clear, is mounted on a heavy spindle at the axle housing, allowing for movement in a horizontal plane; while at its forward end, which is made in the form of a yoke, it is carried on a horizontal pin permitting a vertical movement to compensate for variations in the vertical distance between the axle and frame caused by the compression and recoil of the springs. Its location is made clear in the chassis view, Fig. 53.

Fig. 54 shows the form of mounting adopted by the Timken Company for the David Brown type of worm drive which they manufacture. This is the same as that employed on the Pierce trucks, but both the method of mounting and the bearings differ. The Timken Company use their own taper roller bearings, while the Pierce Company use annular ball bearings. The worm is of the so-called straight type, meaning that it is of uniform diameter throughout its length as distinguished from the "hourglass" type.

Standard Types of Worm Gears. In the straight type, the worm is cylindrical through its entire length, and the worm wheel into which it meshes is concave. In the hourglass type, both worm and worm wheel are concave. The advantage claimed for the latter form is the greater area of engagement, thus spreading the driving strain over a greater number of teeth and reducing the pressure on the surface of both. On this type, however, there is only one position in which the worm and the worm wheel can be located with respect to each other in order to take advantage of this greater area of con-

tact, while on the straight type it is necessary only to locate the worm correctly, with respect to the worm wheel, in one direction, since the worm is cylindrical and uniform in diameter throughout its entire length. The straight type is therefore much less liable to damage through misalignment. With the hourglass type, a slight misplacement in any direction is liable to prove fatal, so that the chances of trouble in practical operation are greatly reduced in the straight type.

Efficiency of Worm Gears. In an elaborate test of three different types of worm gears (by types in this connection being meant

Fig. 54. David Brown Type of Worm Gear as Mounted on Timken Axle

differences in tooth form and pitch) made at the Brown and Sharpe plant to determine which form was best adapted to automobile use, efficiencies ranging from 90.2 to 95.5 were obtained on the first speed, 91.3 to 93.4 per cent on the second speed, and 90.1 to 97.6 per cent on the direct drive. The results obtained with a bevel-gear-drive test made for comparison were 91.4 to 96.6 per cent on first speed, 94.5 to 99.3 on second, and 94.0 to 99.2 on direct drive. So far as the life of the worm is concerned, mileage records obtained on commercial cars range from 40,000 to 110,000 miles, the lower figure

being considered only fair for a well-made straight type of worm; while, on pleasure cars, three years of constant service was not thought at all unusual.

Double-Reduction Live Axle. As sufficient drop in speed cannot be had with a bevel gear through a single reduction without making the driven bevel gear of impracticable proportions, thus involving excessive weight in the rear-axle housing and a dangerous lack of clearance between the latter and the ground, an intermediate spur reduction is introduced just forward of the bevel gears. One method of accomplishing this is illustrated by Fig. 55, which shows the extra speed reduction combined in the same housing as the differential and the bevel drive, an extra cover plate making it accessible. It will be noted that helical-cut gears are employed

Fig. 55. White Differential, Showing Second-Reduction Gear

instead of the straight-spur type, this form of tooth giving greater bearing surface, closer engagement, i.e., less backlash, or lost motion, between the gears and far less noise in running. Another form of double-reduction axle is the special type developed on the Autocar delivery wagon and illustrated in connection with the description of that vehicle.

Internal Gear-Driven Axle. The internal gear-driven type of axle is another form of final drive that has been introduced in this country after a long and successful record abroad. Like the worm gear, it aspires to the honor of replacing the side chains and, like that form, also has already made considerable progress in this direction. In principle, this form of drive consists of making the driving axles independent of, and external to, the rear axle proper, which, in this case,

is of the "dead" type, usually a solid section, such as a square or an I-beam forging. Its function is merely to carry the weight of the car, although it also is made to serve both as a support and as a reinforcement for the live axle. In the case of the Mercedes (German) trucks, on which it has been used since 1900, the driving axle is placed forward of the dead axle. At their outer ends, the shafts of the latter carry small spur pinions which mesh with large internal gears cut on rings attached to drums on the rear wheels. One of these wheels and the driving pinion on the end of the live shaft are illustrated in Fig. 56, which shows this construction as carried out on an American-built replica of the German truck in question.

This same form of axle has been employed also for a number of years in Paris by the builders of the De Dion cars for their commercial types, chiefly busses. In this case, the live axle is carried above

Fig. 56. Mercedes (German) Internal Gear Drive, Showing Principle of Action and Assembled Rear Wheel

its support. More than a hundred of these busses have been in service in New York for several years and, as more are ordered from time to time to meet the increasing requirements, it must be concluded that they have been satisfactory. The builders of the Mais trucks were doubtless the pioneers in the commercial use of this form of axle in this country, and the Mais internal gear-driven rear axle is probably the form in which this type is most generally used. In this case, the driving axle is placed forward of the dead axle. Upon comparing the size of the driving pinion at the rear wheel with the internal gear, it will be apparent that a very large gear reduction is conveniently obtainable by this method without in any way interfering with the road clearance of the vehicle. The first reduction consists, of course, in every case, of the conventional bevel-gear drive, but, as will be noted from the part sectional views of the Torbensen and Garford

types of internal gear-driven axles, as shown in Figs. 57 and 58, there is very little reduction between the bevel pinion and its gear. This decreases the amount of leverage the pinion has to exert and conse-

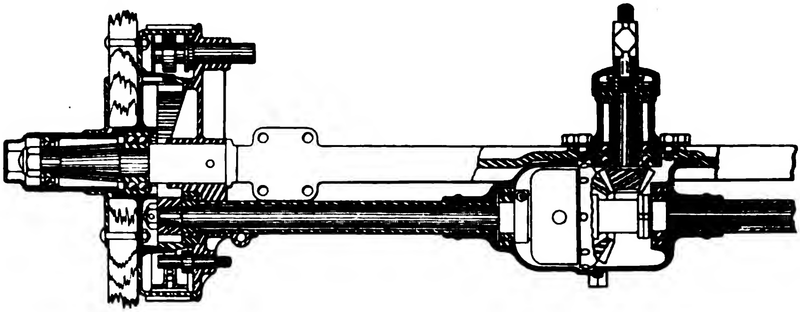

Fig. 57. Torbensen Internal Gear-Driven Rear Axle

quently decreases the tooth pressure in proportion. In the Torbensen axle, the live member, or countershaft, is placed to the rear of the I-beam supporting member, while in the Garford this is reversed. On the Jeffery "Quad", it is placed directly over the wheel support, as

Fig. 58. Garford Internal Gear-Driven Rear Axle

shown by Fig. 59, which illustrates the driving pinion and the wheel with its internal gear. As this truck steers, drives, and brakes on all four wheels, a universal joint is placed directly behind the pinion. Fig. 60 shows the wheel and its gear ready for mounting. A some-

what similar design is found on the Christie front-drive tractor for fire apparatus, with the added distinction that on this machine only the rim of the driving wheel revolves and is carried on a ball bearing which is practically the size of the wheel itself. On the Jeffery, the wheel revolves on the two taper roller bearings shown.

Differential Lock. The function of the differential, balance gear, or compensating gear, as it is variously called, is naturally the same on the commercial vehicle as it is on the pleasure car, i.e., that of permitting one wheel to run free in rounding a turn so that it may travel the greater distance represented by the outside circle in the same time that the inner takes to traverse its orbit; but the differential has the unfortunate drawback of not permitting any power to reach one of the driving wheels in case it is held while the other is free. This frequently occurs where the truck settles into a ditch or extra deep rut in a soft road, leaving the other wheel more or less in the air. Under such conditions the entire power goes to the free wheel, making the problem of extricating the machine from this predicament much more difficult. To overcome this disadvantage of the balance gear, it is customary to provide a differential lock. One form of this lock is illustrated in Fig. 61. On the right-hand side a four-jaw clutch is keyed to the drive shaft, but is left free to slide into mesh with its corresponding member on the differential housing to permit of locking the differential gears. This clutch is operated through a suitable linkage from the driver's seat. By locking the differential, the sunken wheel will pull itself out if the truck is capable of exerting the necessary power.

Fig. 59. Jeffery Rear-Axle Driving Mechanism and Bearings

Front Drives. *Early Development.* One of the earliest applications of power proposed for road locomotion was the attachment of a self-contained power unit to existing horse-drawn vehicles, and a number of different types of such units were built in Europe in the early days of the industry. For some reason, none of them developed to the point of a commercial success. The front-wheel drive, which seems to have been discarded almost entirely for some years, has recently come to the fore again and has been developed very successfully for fire apparatus, on which both mechanical and electrical methods of transmission have been utilized.

Fig. 60. Jeffery Wheel with Internal Gear Ready for Mounting on Axle

Electric Front Drive. The electric front drive has been utilized in numerous lines of business, more particularly for brewery and municipal service, for several years; the Couple-Gear type of electric motor wheel, previously described in the section on the transmission of power on electric cars, was employed for this purpose. In some instances, a single power wheel is used to haul a dump cart or similar slow-moving vehicle; or a unit, comprising a storage battery, controller, steering gear, axle, and two of these power wheels, is permanently coupled to a truck in place of the axle and wheels used when drawn by horses.

The power to drive these motors may be supplied by the current from a storage battery or from a gasoline-electric generator. The

Fig. 61. Bevel-Driven Commercial-Car Axle Fitted with Differential Lock

Fig. 62. Electric Front Drive Using Couple-Gear Motor Wheels

dynamo supplies the power directly to the wheel motors through a three-point controller, there being no other intermediate electric

member. This controller is fitted with two forward speeds and a single reverse, the speed and amount of power utilized being controlled chiefly by means of the spark lever and the throttle of the gasoline motor in the conventional manner. Fig. 62 illustrates a fire engine gasoline-electric tractor using Couple-Gear drive.

Four-Wheel Drives. To meet the requirements of military service, a truck must be able to travel "wherever a team of mules can haul a load". Consequently, like that useful quadruped, it must be equipped with power-transmitting members at all four points of contact with the ground. While the conventional type of truck with one or the other of the standard forms of transmission driving only two rear wheels has proved eminently satisfactory for service wherever a solid roadbed or its equivalent is to be found, it is of little use off the beaten track. Ditches, soft ground, sand, and mud, which do not even embarrass the army mule or, for that matter, the average team of farm horses, render the average motor truck absolutely helpless. To be able to extricate itself from bogs and ditches, it is necessary to be able to "git up and git" on all fours.

To take advantage to the full extent of this form of transmission, the majority of four-wheel-driven cars both drive and steer through all the wheels. Accomplishing this presents no particular mechanical difficulties. Three forms of drive have been developed for this purpose; one in which the power is transmitted through bevel gears mounted on the steering knuckle, while a second employs the internal-gear type of drive using universal joints on the driving shafts just back of the wheels. The third type drives directly to the hubs of the wheels through hollow steering knuckles. This last type presents the simplest layout and was one of the first to be developed in this country on a commercial scale, having been built for several years by the Four Wheel Drive Automobile Company.

This transmission is a simple modification of the three-speed individual-clutch type transmitting the power through a broad silent chain to a parallel shaft placed at the left to clear the engine. This can be seen more clearly in the photograph of the chassis, Fig. 63. This chain also serves as the first reduction in the speed, the second being through the conventional form of bevel gears at the rear and front axles. Each of these bevel-gear drives incorporates a differential for balancing the tractive effort at the wheels, while a third

differential centrally placed on the parallel driving shaft balances the amount of power transmitted to each pair of wheels. This third differential is built in the large sprocket of the silent-chain drive and is provided with a locking device controlled by the driver. A brake

Fig. 63. Chassis of Four-Wheel Drive Truck

drum is mounted on the parallel shaft on either side of the main differential. These transmission brakes are for regular service, the emergency brakes being mounted in drums on the rear wheels.

Fig. 64. Chassis of Jeffery "Quad", Showing Four-Wheel Drive

Owing to their location, the former retard all four wheels simultaneously. There are, of course, four universal joints. Steering is accomplished by means of the front wheels only, so that the rear axle is of the conventional full-floating construction.

Jeffery "Quad". This truck is representative of the second class, or internal gear-driven type mentioned, and has been developed particularly to meet the United States Army requirements. The motor is a four-cylinder block-cast type with L-head cylinders rated at 32 horsepower and is fitted with duplex ignition, i.e., using

Courtesy of Horseless Age

two sets of spark plugs simultaneously. The motor is offset to the right side of the frame and mounted on a three-point suspension, as shown by the plan view of the chassis, Fig. 64. The drive is by shaft to a centrally placed four-speed selectively operated gearset of the sliding-gear type, but the latter differs from the conventional

form of this type of gearset in that it has no direct drive. The propeller shafts are gear driven from the layshaft of the transmission, this construction bringing the forward one sufficiently to one side to clear the motor. Three differentials are employed, one on each axle and one in the gear box, all being of the Wayne gearless type. Both axles are "dead" and are fitted with steering knuckles. The transverse driving shafts at either end are placed above the axles and springs and have universal joints just inside of the wheels and directly over their steering pivots, as shown by the sectional view, Fig. 65. The driving pinion is supported from the steering knuckles between two taper roller bearings and drives an internal gear mounted in the enlarged wheel hub. Bolted to this large hub and the wheel itself is

Fig. 66. Chassis of Jeffery "Quad"

a pressed-steel drum for an external brake, a dust-excluding felt packing being fitted between the drum and the gear ring. The ability of the four-wheel drive to extricate itself from heavy mud and sand with the same amount of power is due to the tendency of the front wheels to climb over obstacles and, at the same time, assist in the propulsion of the weight. Enclosed wheels are employed to cut down the resistance, Fig. 66.

Electric Transmission

Advantages. The practice of utilizing electricity for power distribution in manufacturing plants was already well established before the advent of the automobile on a commercial scale, and attempts were made at an early day to utilize its advantages for transmitting

the power on the latter. Despite the numerous difficulties met with at the outset in the application of the sliding-gear transmission, the employment of electricity has never become as general as its advantages would appear to warrant. A great amount of experimental work, however, has been done, and numerous different systems evolved. Probably the only example of the consistent employment of electric transmission at the present date is to be found in its use on gasoline-electric-railway motor cars, of which quite a number are in service. As the limitation of weight, one of the most important factors to be considered on the automobile, is lacking in this application, it can hardly be said to represent an exact parallel.

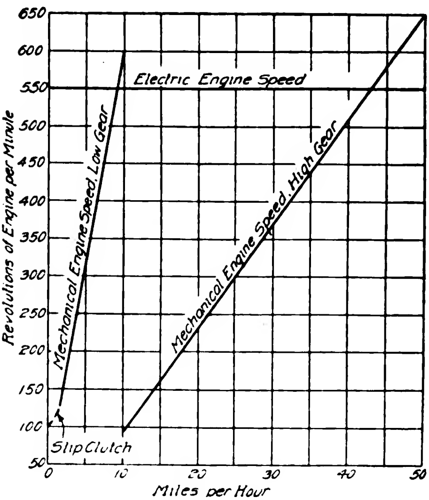

Fig. 67. Curves Showing Variations of Engine Speed for Gasoline-Electric Transmission

One of the chief advantages of the employment of electric transmission is the possibility of running the gasoline motor constantly at its normal speed, at which it develops its rated output most economically and with a minimum wear. The sharp contrast between the speed variations required of the gasoline motor employed with a mechanical transmission and with one of the electrical type is shown by the curves in Fig. 67. With the electric transmission, the gasoline motor speed remains constant from the time of starting right up to 50 miles an hour.

Several Systems. To those familar with electric practice it will be plain that several methods of utilizing electricity for the transmission of the power on an automobile are available. In general, however, they may be divided roughly into three divisions. The first of these is simply a replica of that commonly employed in manufacturing plants, i.e., mechanical energy as produced by an engine is converted into electrical power, transmitted to an electric motor at a distance, and there reconverted into mechanical energy. This

double conversion naturally entails a loss of efficiency; but, in manufacturing practice, this is considerably less than where the power is directly transmitted from the engine to the tool at which it is to be used, and the efficiency increases with an increase in the distance between the two.

The second system involves the conversion of mechanical into chemical energy in the storage battery, from which the current is drawn to operate electric motors in the usual way, Fig. 68. This is really a self-contained electric in that it carries its own charging plant, with the further advantage, however, that the excess capacity of the generator is always available for driving the vehicle. Or, to put it

Fig. 68. Couple-Gear Gasoline-Electric System

the other way around, the greater part of the current from the gasoline motor electric-generator unit is employed for running the car, and the excess current utilized for charging the storage battery, which is then said to be "floated on the line."

The third system is based on the principle employed in the cradle type of electric dynamometer, in which an electric generator is so mounted that its field may revolve in response to the drag exerted on it by the armature, this tendency being counteracted by a balance lever attached to the field. By means of weights placed on this lever, the effort exerted may be accurately weighed, and the power developed by the prime mover driving the generator may be calculated within close limits.

DETAILS OF CHASSIS AND RUNNING GEAR

Springs

The problem of providing a form of spring suspension that will not be overstiff when the car is empty and still provide sufficient holding powers to withstand rough road work with a full load, which the designer of the touring car has had to face, is aggravated a hundredfold on heavy trucks. Between the "load" and "no load" points of the pleasure car, there is a comparatively small range. When a touring car weighing 4000 pounds, all on, has its full load of seven passengers averaging 150 pounds each, their combined weight represents only 25 per cent of the weight of the vehicle itself, but when a 5-ton truck, weighing slightly over five tons when empty—say 11,000 pounds—receives its full load of five tons plus anywhere from 10,000 to 14,000 pounds, the increase, instead of being from 0 to 25 per cent, is from 0 to 100 per cent plus. There is also the far greater tendency to side sway, owing to the height at which the load is ordinarily carried.

Fig. 69. Principle of the Compensating Spring Support Employed on Heavy Trucks

Semi-Elliptic Usual Type. As it permits keeping the center of gravity down, gives less recoil under heavy shock, and is less subject to lateral stresses, the flat semi-elliptic type of spring is almost universally employed on commercial vehicles, from a delivery wagon up to a 7-ton truck. By delivery wagon in this connection is meant the type specially designed for commercial service and not the converted touring-car type in which pleasure-car standards remain unaltered, and the high three-quarter elliptic spring at the rear is not uncommon.

It will be apparent, however, that no form of spring suspension would be sufficient in itself to cover such an extended range of loading as that mentioned and still give even a fair approximation to efficiency at either extreme. Maximum carrying ability is the chief thing to be provided, and using springs that will do this alone would be an easy matter; but the problem is to guard against the maximum

stresses to which the springs will be subjected under heavy loads and still have a suspension that will prevent the motor and driving mechanism of the truck from being pounded to pieces when the vehicle is running without a load. To achieve this, it is customary to employ rocking shackles at one end and some form of sliding, or compensating, support at the other, although in numerous instances the springs are shackled at both ends in the same manner. As the driving strain is practically always taken on radius, or distance, rods in the case of side-chain-driven cars, and on torque rods on cars of the shaft-driven type, there is ample altitude for variation in this respect.

Principle of Compensating Support. The sketch, Fig. 69, illustrates the principle upon which all compensating supports for the springs is based. Of course, this applies only to the rear-wheel springs, which are usually called upon to bear anywhere from 60 to 85 per cent of the useful load. The front springs are usually pinned to the dropped dumb ends of the frame forward and shackled to brackets at their rear ends. The front end of a rear spring is shown by the illustration. Given a suspension sufficiently stiff to withstand the maximum load of which the truck is capable, it will be apparent that when empty the body will be lifted and the sliding end of the spring will be against the right-hand end of the support. The spring is then under its minimum compression and will respond more readily to shock.

Brakes

Usual Types. In as much as the greater loads carried far more than offset the lower speeds at which commercial cars travel as compared with the pleasure type, there can be no comparison of the braking requirements of the two. This is particularly the case in as much as the greatest strain does not come on the brakes because of the infrequent necessity for stopping suddenly but on account of their continued use in holding the loaded truck back on long hills. Commercial-car brake design naturally varies with the type of vehicle and likewise with its carrying capacity. On light delivery wagons, the type employed is the same as used on touring cars, viz, internal-expanding and external-contracting asbestos-fabric-lined shoes in pressed-steel drums on the rear wheels. In some instances, the practice, usually confined to the higher-priced pleasure cars, of placing the two sets of brakes side by side so that they contact on the same

drum and can be enclosed against the entry of dirt and water, is also found. An example of the first type mentioned is shown in Fig. 70, which illustrates a Timken worm-driven rear axle. The brakes on the Reo chassis are shown in Fig. 71.

Braking All Wheels. Considerable discussion has arisen from time to time regarding the advisability of braking on all four wheels;

Fig. 70. Timken Worm-Driven Rear Axle, Showing Brakes

but, prior to the advent of the four-wheel drive, this was tried in only a comparatively few instances. In addition to providing greater retarding power, the advantage of eliminating the tendency to skid has also been attributed to the front-wheel brake. When all four

Fig. 71. Brake Detail, Reo 2-Ton Chassis

wheels are driven, brakes are applied to all simultaneously, the braking effort at each wheel being equalized by a compensating device. On the Jeffery "Quad", these brakes are applied directly to the wheels themselves and consist of a simple and well-worked-out internal-expanding cam-actuated type, as shown by Fig. 72.

TRAILERS

Utilizing Excess Power. Trucks, like all other motor vehicles, must necessarily be equipped with power plants capable of successfully meeting exceptionally severe conditions imposed by heavy grades and by muddy, sandy, and snowy road surfaces, as well as the normally easy grade and road conditions encountered by the average truck during a very large proportion of its service. Hence, there is a large reserve power-plant capacity idle for a great part of the time. From the economic standpoint, it is a wasteful condition for a truck with sufficient power to handle a ten-ton load on smooth

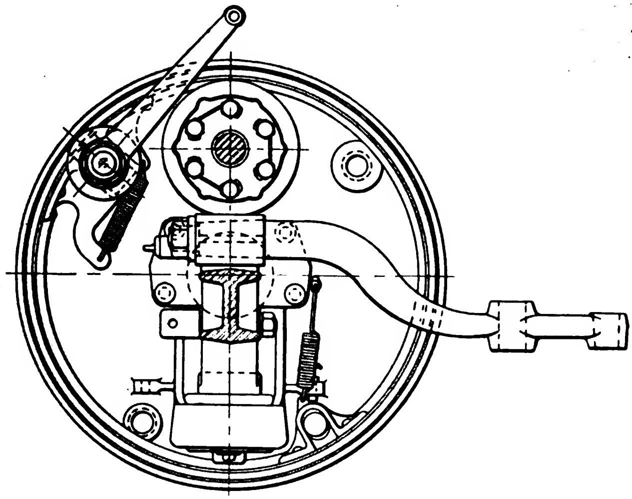

Fig. 72. Internal Expanding Cam-Actuated Type of Brake Employed on the Jeffery "Quad"

level roads to be restricted to the five-ton load which its structural parts permit. This applies proportionately to all sizes of commercial vehicles, from the very lightest up, and it accounts for the widespread use to which trailers are being put.

Two-Wheel Types. For light- and medium-capacity service, trailers can be made with only two wheels, thus keeping the wheelbase of the double unit down and permitting of much higher speeds. Trailers designed for use in connection with the lightest types of delivery wagons, such as the Ford, or for the thousands of ex-touring cars that are spending the second period of their existence in a commercial rôle, usually carry a load of about 400 pounds. They are

made to fit any standard make of automobile, a special bracket being fitted to the rear of the frame of the car. Connection is made by means of a tongue fitted with a swiveling pin and locked with a thumb nut, so that the trailer may be attached or detached quickly without using tools; the pin in question, together with the fact that the trailer has only a single axle, allows for universal relative movement between it and the towing car.

Four-Wheel Types. It is in the employment of what is practically a second truck, where its carrying capacity is concerned, that the use of the trailer shows the greatest operating economy, and

Fig. 73. Troy Trailer for Motor Trucks

specially designed vehicles have been developed for this purpose. The builders of the Troy wagons have evolved a special type of trailer for the motor truck, as shown in Fig. 73.

Troy Trailer. It will be noted upon referring to the illustration, Fig. 73, previously mentioned, that the construction of the Troy trailer is along very similar lines to those generally followed in motor-truck construction. In fact, the trailer is practically a motor truck without power and, as it is subjected to even heavier loading and more severe strains than the latter, is built accordingly.

Both sets of wheels are designed to steer and are controlled by the drawbars at each end of the trailer, the cross-connecting rod of

the steering gear being attached to the under side of the drawbar near its rear end. As the drawbar follows its towing truck around corners, it also serves to swerve the front wheels of the trailer in the same direction.

GASOLINE-DRIVEN TRACTION ENGINES

Greatest Field of Usefulness. Under this head falls a type of machine which might be thought of as hardly coming within the category of the commercial vehicle at all; but it represents an extremely important branch which is just beginning to come into its own and which, in the course of the next ten years or so, is destined to prove a powerful factor in the elimination of the horse from many classes of work now entirely monopolized by animal traction. Thus far, haulage has formed only a comparatively small part of the work of the gasoline traction engine and probably will not be generally used for this purpose for some time to come. So far, its greatest value has been in the carrying out of purely agricultural operations on the large scale demanded by modern farming.

MECHANICAL DETAILS

Motor Design. Students of automobile engineering will recall that the first attempts at automobile design in this country consisted of nothing more than the adaptation of the ordinary stationary engine to a running gear, and, further, that it was the dogged adherence to this abortive combination that did so much to keep the American automobile so far behind its European competitors in the first years of the last decade.

The early agricultural tractors were likewise little more than stationary engines of the horizontal type, mounted on a running gear suited to the needs of the machine. The design was not as poor a one for the purpose as was the case with the automobile, since the conditions of service are totally different. Speeds are necessarily very low, as plows or other tools cannot be handled properly at a rate of travel in excess of a few miles an hour, while weight is a desideratum rather than otherwise, in order to obtain the tremendous tractive power needed to start and haul loads involving such a great drawbar pull as is required to break a number of furrows in hard soil.

The practice of simply mounting a stationary engine on wheels, which characterized early agricultural tractor design, has been practically abandoned and in its place has come a tendency to adopt the automobile motor pretty much as it stands. Between these two extremes are found motors which have been specially designed for this form of service and which accordingly reflect the trend that future developments are apt to take better than does either of the others. Not that some of the automobile types of motors have not been specially built for the purpose, which is probably the case in most instances where they are used; but it is to be questioned whether

Fig. 74. Secor Kerosene Engine of Rumely Tractors

the light, high-speed type of motor is the best form of power plant for such heavy, slow-moving machines.

Rumely Kerosene Motor. The agricultural tractor, to be generally adopted, must be capable of operating on a cheap and universally obtainable fuel. At present, the only fuel that fills this requirement is kerosene. Gasoline cannot be shipped on passenger steamers, while railway freight on it is so high for long hauls as to make it almost prohibitive in some parts of this country, notably in the states of the great western plains; hence, most tractor motors are fitted to use kerosene, including those used on the Rumely tractors.

These motors are built in two sizes. The smaller size is a single-cylinder 15-horse power unit, while the larger is a two-cylinder, the constructional details of the last named being made plain by the phantom view, Fig. 74. They operate on the Secor-Higgins principle,

Fig. 75. Details of Transmission, Samson Tractor

which, in brief, is that of mixing water directly with the fuel, the amount being regulated automatically in accordance with the load. At the moment of explosion in the cylinder, the water is evaporated and dissociated into its elements—hydrogen and oxygen. As the

piston advances and the temperature drops, some of it is converted into steam and liberates its heat, thus maintaining the pressure over a longer proportion of the stroke, so that the engine develops a high mean effective pressure on a comparatively low initial compression. In addition to facilitating the combustion of the non-volatile fuel, the nascent oxygen liberated has a high affinity for carbon and materially assists in keeping the cylinders clean, while hydrogen has a fuel value and is highly explosive when mixed with the proper proportion of oxygen, so that it also assists in the quick and thorough combustion of the kerosene.

Multi-Cylinder Motors. As already mentioned, these motors follow the standards which have become familiar in automobile motor design. They are usually of the four-cylinder vertical type, and their construction and auxiliaries are practically identical with those ordinarily employed on automobiles. In fact, the builders of the British Daimler tractors employ the same Knight sleeve-valve engine on these machines that they do on their high-priced pleasure cars. The four-cylinder motor employed on the Samson tractor is shown incidentally in Fig. 75, this illustration being chiefly intended to reveal the details of the type of transmission employed.

Transmission. In this essential, a radical departure from automobile practice must naturally be followed, in view of the very low speeds—usually not exceeding 2 to 2½ miles per hour for plowing—and the tremendous tractive effort that must be exerted in hauling a gang plow through heavy wet soil; consequently, it would be out of the question to build the transmission in the form of a small gear box, as is done on automobiles. While motors of the automobile type are employed, their speed is usually very much lower; the motor of the Samson tractor, for example, running at 525 to 575 r.p.m. Still, to give the two forward speeds of 2 and 4 miles an hour, it is evident that there must be a great reduction between the motor and the driving wheels, particularly as the wheels are very large and make comparatively few revolutions per mile. A double-drum expanding friction clutch is built in the large bevel gears to form the first step in the transmission, a small spur pinion on the same shaft as the large bevels meshing with a large spur gear on a transverse shaft. The latter carries two fixed gears, while a sliding pair is mounted on a parallel shaft just forward of it. When the left-

hand one of these is meshed with the left-hand fixed gear, the tractor drives at 2 miles an hour through still another speed reduction between the second transverse shaft and the rear axle. By meshing the right-hand gears, the higher speed is obtained. It will be noted that there are four different steps in the speed reduction between the motor and the rear axle and that the gears and shafts are of large dimensions.

TYPES

Rumely. The Rumely tractor, shown in Fig. 76, is a close approach to what may be regarded as standard practice in this field,

Fig. 76. Rumely Kerosene Engine Tractor

so far as its construction details are concerned. It takes but a glance to recognize the influence of the steam traction engine and the steam road roller of American design. One of these machines, which hauls a gang plow turning eight furrows, is shown in Fig. 77.

International. The International tractor is practically nothing more than one of the stationary engines made by this company, mounted on the platform of a heavy, four-wheeled truck, Fig. 78. The engine in question is of the single-cylinder long-stroke type, with the valves in the head, the exhaust valve being mechanically operated, while the inlet valve is automatic. The governor, as is customary in stationary practice, is of the hit-and-miss type acting on the exhaust

valve. In governors of this class, centrifugal force is taken advantage of to make the exhaust-valve rod hit or miss the valve tappet, opening the latter or allowing it to remain open, according to the speed and

Fig. 77. Kerosene Tractor Hauling Heavy Gang Plow

Fig. 78. Gang Plow and Gasoline Motor Tractor in Heavy Soil

the requirements of the load. As the automatic inlet valve depends upon atmospheric pressure for its operation, it cannot open unless the exhaust valve has closed on the stroke just preceding, so that no

fuel enters the combustion chamber except when an explosion is necessary. As the governor is also usually designed to trip the igniter mechanism out of action at the same time, such engines are very economical of both fuel and electric current. The cylinder is of large bore, and a low compression is employed as compared with automobile motor practice, two huge flywheels being utilized to give the engine a smooth-running balance. The engine is cooled by means of a modified form of water tank placed forward. This tank is provided with a large wire-gauze screen with sloping sides, over which the hot water is sprayed immediately on leaving the water jacket; the water is then collected in the tank below and circulated.

The drive wheels are entirely of metal, having a 56-inch diameter and an 18-inch face; they have heavy lugs bolted to the tires to provide ample traction, even on soft ground. Two friction clutches are employed, a large one for the forward speeds and a smaller one for the reverse. The drive is through two sets of pinions and large gears, a sliding pinion on the crankshaft of the engine driving a large differential gear on a countershaft carrying two pinions at its outer ends, which engage large gears on the road wheels. Reverse is obtained by shifting a lever which throws the large clutch out of engagement and engages the small one driving an intermediate gear. The same lever gives both the forward and reverse speeds, while a foot lever applies a band brake that operates on the differential.

The foregoing serves to describe the small-size International tractor, which is fitted with a 15-horsepower single-cylinder engine, although it generally covers the construction of the larger sizes also.

Hart-Parr. The Hart-Parr tractor, which has achieved considerable success, was one of the first to depart from the practice of employing the ordinary stationary engine as its motive power. As will be seen from the illustration, Fig. 79, the engine is of the two-cylinder horizontal type, the cylinders being placed beside each other and having all the valve mechanism in the head, which makes it very accessible. The crankshaft has the two throws placed 180 degrees apart, so that the heavy pistons are always moving in opposite directions. This gives an excellent mechanical balance and accounts for the single flywheel of greatly reduced size. The use of an auxiliary exhaust valve, or port, uncovered by the piston just before

the end of its outward travel on the power stroke, is also a feature of this engine and insures cool running under the heaviest loads.

An original and ingenious system of oil cooling is employed, making it unnecessary to take any precautions to prevent freezing in

Fig. 79. Motor of Hart-Parr Traction Engine

Fig. 80. Hart-Parr Traction Engine

cold weather. As will be seen from the illustration of the complete Hart-Parr machine, Fig. 80, this system consists of a special type of radiator mounted on the forward end of the platform. This radiator

is formed of a number of thin corrugated sections covered by a conical hood and a short stack. The supply of oil is circulated through these sections of the radiator and through the jackets of the cylinders by means of a centrifugal pump mounted directly on one of the cylinders. The exhaust from the engine is led into the hood over the radiator, and in the upper faces of the exhaust pipes under the hood are drilled a large number of small holes, causing the exhaust gases to be discharged upward in numerous fine jets, which not only act as a muffler, but also set up a strong draft of

Fig. 81. Samson 3-Wheel "Sieve-Grip" Tractor

air through the radiator. As the oil never reaches a temperature sufficiently high to boil it and there is therefore no waste, the original supply should last as long as the engine, barring accidents. The engine is capable of delivering 45 horsepower, according to the usual rating, but as the machine is intended to displace 22 draft horses, the tractor is given a nominal rating of the latter figure.

Samson. In contrast with this, the Samson, which is built on the Pacific Coast, represents a much closer approach to a three-wheel automobile or at least to an automobile tractor. Apart from

its motor and transmission, which have already been referred to, this machine is distinguished by the use of what is termed *sieve-grip* driving wheels. These will be noted more in detail in Fig. 75, from which it will be plain that they are in reality skeleton wheels, the treads of which consist of series of angle bars riveted to their supports in a staggered relation to one another where the two wheels are concerned, thus giving the maximum traction. One of these tractors is shown in service in Fig. 81.

Johnson. Fig. 82 illustrates a tractor of this type in service—plowing an orange grove—and shows that it differs radically from either of the foregoing. Like the Samson, it is a three-wheeler; but there the resemblance between the two ends. The engine is

Fig. 82. Johnson Agricultural Tractor Plowing an Orange Grove

placed horizontally and drives through side chains and sprockets, which accounts for a large part of the speed reduction necessary. Instead of depending upon the natural movement of the air to assist in cooling the radiator, the latter is carried in a housing which contains a high-speed fan and which provides the necessary draft.

Auto-Tractor. As the time is already at hand when even a greater proportion of the farming population boasts of automobiles than city dwellers can be credited with, this tractor has been so designed as to enable the farmer to use his car for actual farm work in addition to its other services. The tractor accordingly consists simply of a long steel frame, a pair of standard steel tractor wheels fitted with a gear drive, and a standard automobile radiator, as will

be seen in Fig. 83. The only modification required on the automobile itself is the fitting of a pair of small spur gears to the rear wheels. The car is backed up over the tractor frame, and ropes

Fig. 83. Auto-Tractor Ready for Attachment

attached to the rear of the tractor are then passed around the hubs of the rear-wheel gears mentioned. By running the car in reverse, it hauls itself up the incline of the frame until the rear axle rests in bearings provided for it. At this point, the wheel pinions mesh

Fig. 84. Method of Mounting and Attaching an Automobile to the Auto-Tractor

with large spur gears of almost the same diameter as the tractor driving wheels. The front end of the tractor frame is then lifted and made fast to the forward end of the car frame, the connections of the extra radiator on the tractor are made with the cooling system

of the car, and the automobile is ready to run as a tractor. Fig. 84 shows the car hauling itself into place on the tractor frame. When attached to the tractor, the automobile motor may also be utilized as a stationary engine.

In addition to the speeds available on the automobile, the tractor gearing also provides two speeds which permit the machine to travel at 2 or 4 miles per hour. The power is taken from the hub gears on the automobile close to the center of the axle instead of from the tire; and, as the weight of the car is entirely removed from the rear axle and there are no road shocks, the most injurious features of ordinary automobile operation disappear. The gearing is so designed that the car is run on high speed entirely, even when starting under load, although the intermediate speeds may be resorted to in case of extra heavy pulls. This means that when the tractor is plowing at the rate of two miles per hour, the automobile engine is running at its normal speed of 800 to 1000 r.p.m., at which speed it is designed to give its best efficiency and run constantly without strain. The use of one of these tractors in an Oregon orchard is said to show a reduction from $3.40 per acre per year with teams to $1.20 per acre per year with the machine, the cost per acre for each cultivation with the machine being only 24 cents.

Holt Caterpillar Tractor. For agricultural operations in alluvial lands, reclaimed swamps, and rice fields, or other ground so soft that the wheel type would become mired, the so-called *caterpillar* tractor has been developed. Tractors of this type have been in successful operation in various parts of the world for a number of years. They are built in two sizes, 30- and 60-horsepower. Fig. 85 shows one of the smaller size and makes the appropriateness of the title apparent. Apart from the variation in dimensions, the only difference between the two is the provision of a forward steering truck on the large tractor. From an engineering point of view, the Holt tractor is of more than usual interest, as it is the only form of locomotion not involving the use of wheels in contact with the ground.

As its name indicates, the tractor literally crawls over the ground by means of blunt-toothed endless chains. This must not be taken to signify that its speed is simply a crawl, as the tractor illustrated hauls a gang plow at the rate of 2½ miles an hour, plowing speeds for tractors generally being from 2 to 2½ miles an hour, regard-

less of type. The motor is a four-cylinder vertical gasoline engine of special design, the cylinders being cast independently with separable heads. The valves are placed in these heads and operated by rocker arms from a single camshaft. To provide the maximum accessibility, the crankcase is of practically the same height as the cylinders and is provided with large handholes through which the pistons can be withdrawn; in fact, the crankshaft can be taken out without disturbing the cylinders, manifolds, or ignition system. A dual-ignition system, comprising a high-tension magneto for running and a battery-and-coil auxiliary for starting; constant-level splash-

Fig. 85. Holt Caterpillar Tractor for Plowing

lubricating system with an auxiliary force-feed oiler supplying oil directly to the main bearings; a Schebler carburetor; and a centrifugal pump for circulating the cooling water constitute the motor essentials. Two flywheels are fitted, one of them being of unusually liberal diameter and weight which permits the motor to develop its rated output at the low speed of 600 r.p.m. A standard type of fly-ball centrifugal governor mounted outside the crankcase on an extension of the camshaft and acting directly on the throttle prevents this speed from being exceeded. The cooling system consists of a vertical tube radiator, a fan, and a large water tank, the mounting of the motor and radiator being in accordance with standard truck practice.

Caterpillar Drive. From the motor, the power is transmitted through a multiple-disc clutch consisting of two large bronze discs and three of iron, the former being carried on a steel ring driven by casehardened lugs in the flywheel rim. The weight of the clutch itself is carried by a self-aligning annular ball bearing mounted on the end of the crankshaft. A heavy universal joint interposed between the clutch and the transmission takes care of any relative movement. The relative locations of the motor, clutch, and transmission can be noted in the illustrations of the frame, Fig. 86, the motor being at the right, the clutch in the opening just back of the transverse brace, while the lower half of the transmission case is

Fig. 86. Frame of Holt Caterpillar Tractor

bolted directly to the frame and has the bearings cast in gerally. The forward, reverse, and bevel-reduction gears are located in this case, the final, or main, driving gears, which run in oil, being placed on each side of the housing in the broad troughs shown. A shaft extends outward from each one of these main driving gears and carries on its outer end a spur pinion meshing with a large gear on the same shaft as the sprocket, which is shown at the right of Fig. 85. Each of these sprockets is controlled by a friction clutch so that the two driving units are operated independently, and no differential is required.

Engaging these sprockets are heavy block chains, the links, or blocks, having blunt teeth to give traction in moist ground. As

shown in Fig. 85, the weight of the tractor is carried by five grooved steel wheels on each side, these wheels being mounted on a spring-supported frame. On the upper side of this frame are three heavy rollers to prevent the chain from the sagging due to its weight, while at the forward end it is guided around a plain idler, or free-running pulley. The driving effort is taken on the straight rod that bears on the sprocket shaft at the rear end and is bolted directly to the frame at its forward end. All bearings are lubricated by grease cups. The chain links, or "track shoes", which are detachable, are made heavy enough to withstand the most severe usage. They have curved ends and overlap each other, so that there is no opening

Fig. 87. Holt Caterpillar Tractor Plowing

between them, even when the chain, or "track", is curved around the sprocket. Owing to the great area in contact, there is practically no friction between the shoes and the ground, and the track cannot slip. The truck illustrated is for service on comparatively hard surfaces, its width being increased in accordance with the nature of the ground, and some of the tractors being fitted with tracks 30 inches in width. The upper face of the shoes forms a smooth steel track on which the five weight-carrying wheels run. The rails of the caterpillar track are made high and have openings at the side, so that any dirt falling into the track is forced out through these openings by the teeth of the track sprocket. As each track may be driven separately through its friction clutch, the tractor can turn in practically its own length by driving one of the tracks and letting

the other remain idle, thus causing the machine to revolve almost as if it were on a pivot. Fig. 87 illustrates one of these tractors hauling a disc harrow and a leveling drag.

Avery Tractor. The Avery tractor, shown in Fig. 88, has 5 to 10 horsepower and has developed to meet the demand of the very small farmer, gardener, orchard man, and even the contractor, for hauling purposes, especially in connection with road building and road repairing. This tractor will take the place of an ordinary four-horse team and it can be easily adapted to any operation within its range of power.

Fig. 88. Avery 5 to 10 Horsepower Farm Tractor
Courtesy of Avery Company, Peoria, Illinois

The motor has heavy-duty bearings, large crankshaft, and heavy drop-forged connecting rods; the cylinders are cast *en bloc*, with ample water-cooling space. The wheel-base is 108 inches; two driving wheels in the rear, 38 inches high and 5 inches wide, are provided with internal gears, through which the engine power is delivered by means of compensating gears mounted on the countershaft.

The rear frame is provided with a drawbar having a series of holes crosswise of the machine to which implements or trailers may be attached. The machine will burn gasoline or motor spirits, a tank carrying 11 gallons being provided at the rear of the seat.

GLOSSARY

GLOSSARY

THE following glossary of automobile terms is not intended in any sense as a dictionary and only words used in the articles themselves have been defined. The definitions have been made as simple as possible, but if other terms unfamiliar to the reader are used, these should be looked up in order to obtain the complete definition.

A

A. A. A.: Abbreviation for American Automobile Association.

Abrasive: Any hard substance used for grinding or wearing away other substances.

Absorber, Shock: See "Shock Absorber".

Accelerate: To increase the speed.

Acceleration: The rate of change of velocity of a moving body. In automobiles, the ability of the car to increase in speed. Pickup.

Accelerator: Device for rapid control of the speed for quick opening and closing of the throttle. Usually in the form of a pedal, spring returned, the minimum throttle opening being controlled by the setting of the hand throttle.

Accessory: A subordinate machine that accompanies or aids a more important machine; as, a horn is an accessory of an automobile.

Accumulator: A secondary battery or storage battery. It usually consists of chemically prepared lead plates combined with an acid solution. Upon being charged with an electric current from a primary source, a chemical change takes place which enables the plates in their turn to give a current of electricity when used as a source of power, the plates at the same time returning to their original chemical state.

Acetone: A liquid obtained as a by-product in the distillation of wood alcohol, and used in connection with reservoirs for storing acetylene for automobile lights, as it dissolves many times its own volume of acetylene gas.

Acetylated Alcohol: Alcohol which has been denatured by the addition of acetylene, which also increases its fuel value. See "Alcohol, Denatured".

Acetylene: A gaseous hydrocarbide used as an illuminant; is usually generated for that purpose by the action of water on calcium carbide.

Acetylene Generator. A closed vessel in which acetylene gas may be produced by the action of water on calcium carbide and which supplies the gas under uniform pressure.

Acetylene Lamp: A lamp which burns acetylene gas.

Acetylite: Calcium carbide which has been treated with glucose. It is used to obtain a more uniform and slower production of acetylene gas than can be obtained with the untreated calcium carbide.

Acid: In connection with automobiles the term usually means the liquid or electrolyte used in the storage battery. See "Electrolyte".

Acid Cure. Method of rapid vulcanization of rubber without heat. Used in tire repairs. The agent is sulphur chloride.

Acidimeter. An instrument for determining the purity of an acid.

Active Material: Composition in grids that forms plates of a storage battery. It is this material in which the chemical changes occur in charging and discharging.

Adapter: Device by which one type of lamp burner may be used instead of the one for which the lamp was designed. Usually a fitting by which a gas or oil lamp may be converted into an electric lamp.

Adhesion: That property of surfaces in contact by virtue of which one of them tends to stick to the other. It is used as synonymous with friction. The adhesion of wheels acts to prevent slipping.

Adjustment: The slackening or tightening up of parts to compensate for wear, reduce friction, or secure better contact.

Admission: In a steam engine, the letting in of the steam to the cylinder; in gas engine, the letting in of mixture of gas and air to the cylinder.

Advanced Ignition: Usually called *advancing the spark*. Setting the spark of an internal-combustion motor so that it will ignite the charge at an earlier part of the stroke.

Advance Sparking: A method by which the time of occurrence of the ignition spark may be regulated, by completing the electric circuit at the earlier period.

Advancing the Spark: See "Advanced Ignition".

Aerodynamics: The science of atmospheric laws, i.e., the effects produced by air in motion.

After-Burning: Continued burning of the charge in an internal-combustion engine after the explosion.

After-Firing: An explosion in the muffler or exhaust passages.

A-h: Abbreviation for *ampere hour*.

Air Bottle: A portable container holding compressed air or carbon dioxide for tire inflation.

Air-Bound: See "Air Lock".

Air Compressor: A machine for supplying air under pressure for inflating tires, starting the motor, etc.

Air Cooled: Cooled by air direct. Usually referring to the cylinder of an engine, whose heat caused by the combustion within it is carried away by air convection and radiation.

Air Cooling: A system of dispersing by air convection the heat generated in the cylinder of an internal-combustion motor.

Air Intake: An opening in a carbureter to admit air.

Air Leak: Entrance of air into the mixture between carbureter and cylinder.

Air Lock: Stoppage of circulation in the water or gasoline system caused by a bubble of air lodging in the top of a bend in the pipe.

Air Pump: A pump operated by the engine or by hand to supply air pressure to the oil tank or gasoline tank; sometimes called *pressure pump*.

Air-Pump Governor: A device to regulate the speed of the air pump so as to give a uniform air pressure.

Air Resistance: The resistance encountered by a surface in motion. This resistance increases as the square of the speed, which makes it necessary to employ four times as much power in order to double a given speed.

Air Tube: See "Pneumatic Tire".

Airless Tire: Name of special make of nonpuncturable resilient tire.

A. L. A. M.: Abbreviation for Association of Licensed Automobile Manufacturers, now out of existence.

A. L. A. M. Horsepower Rating: The horsepower rating of an automobile found by the standard horsepower formula approved by the Association of Licensed Automobile Manufacturers. Since the dismemberment of this organization, the formula is usually called the S.A.E. rating. This formula is h.p. = bore of cylinder (in inches) squared × No. of cylinders ÷ 2.5, at a piston speed of 1000 r.p.m.

Alarm, Low-Water: See "Low-Water Alarm".

Alcohol: A colorless, volatile, inflammable liquid which may be used as fuel for internal-combustion engines.

Alcohol, Denatured: Alcohol rendered unfit for drinking purposes by the addition of wood alcohol, acetylene, and other substances.

Alignment: The state of being exactly in line. Applied to crankshafts and transmission shafts and to the parallel conditions of the front and rear wheels on either side.

Alternating Current: Electric current which alternates in direction periodically.

Ammeter: An instrument to measure the values of current in an electric circuit directly in amperes. Also called *ampere meter*.

Amperage: The number of amperes, or current strength, in an electric circuit.

Ampere: The practical unit of rate of flow of electric current, measuring the current intensity.

Ampere Hour: A term used to denote the capacity of a storage battery or closed-circuit primary battery. A battery that will deliver three amperes for six hours is said to have an eighteen-ampere-hour capacity.

Ampere Meter: See "Ammeter".

Angle-Iron Underframe: An underframe constructed of steel bars whose cross section is a right angle.

Anneal: To make a metal soft by heating and cooling. To draw the temper of a metal.

Annular Gear: A toothed wheel upon which the teeth are formed on the inner circumference.

Annular Valve: A circular valve having a hole in the center.

Annunciator: An installation of electric signals or a speaking tube to allow the passengers in an enclosed car to communicate with the driver.

Anti-Freezing Solution: A solution to be used in the cooling system to prevent freezing in cold weather; any harmless solution whose freezing point is somewhat below that of water may be used.

Anti-Friction Metal: Various alloys of tin and lead used to line bearings, such as Babbitt metal, white metal, etc.

Anti-Skid Device: Any device which may be applied to the wheels of a motorcar to prevent their skidding, such as tire coverings with metal rivets in them, chains, etc.

Apron: Extensions of the fenders to prevent splashing by mud or road dirt.

Armature: In dynamo-electric machines, the portion of a generator in which the current is developed, or in a motor, the portion in which the current produces rotation. In most generators in automobile work, the armature is the rotating portion. In magnetic or electromagnetic machines the armature is the movable portion which is attached to the magnetic poles.

Armature Core: The iron portion of the armature which carries the windings and serves as part of the path for the magnetic flux.

Armature Shaft: The shaft upon and with which the armature rotates.

Armature Winding: Electrical conductors, usually copper, in an armature, and in which the current is generated, in case of a generator, or in which they produce rotation in a motor.

Artillery Wheel: A wheel having heavy wood spokes.

Aspirating Nozzle: An atomizing nozzle to make the liquid passing through it pass from it in the form of a spray.

Assembled Car: A car whose chief parts, such as engine, gearset axles, body, etc., are manufactured by different parts makers, only the final process of putting them together being carried out in the car-making plant.

Atmospheric Line: A line drawn on an indicator diagram at a point corresponding with the pressure of the atmosphere.

Atmospheric Valve: See "Suction Valve".

Atomizer: A device by which a liquid fuel, such as gasoline, is reduced to small particles or to a spray; usually incorporated in the carbureter.

Auto: (1) Popular abbreviation for automobile. (2) A Greek prefix meaning self.

Auto-Bus: An enclosed motor-driven public conveyance, seating six or more people; usually has a regular route of travel.

Autocar: A motorcar or automobile; a trade name for a particular make of automobile.

Auto-Cycle: See "Motorcycle".

Autodrome: A track especially prepared for automobile driving, particularly for races.

Autogenous Welding: See "Welding, Autogenous".

Auto-Igniter: A small magneto generator or dynamo for igniting gasoline engines, the armature of which is connected with the flywheel by gears or by friction wheels, so that electric current is supplied as long as the engine revolves.

Autoist: One who uses an automobile.

Automatic Carbureter: A vaporizer or carbureter for gasoline engines whose action is entirely automatic.

Automatic Cut-Out: See "Cut-Out, Automatic".

Automatic Spark Advance: Automatic variation of the instant of spark occurrence in the cylinder. Mechanical advancing and retarding of the spark to correspond with and controlled by variations in crankshaft speed.

Auto-Meter: Trade name for special make of combined speedometer and odometer.

Automobile: A motor-driven vehicle having four or more wheels. Some three-wheeled vehicles are properly automobiles, but are usually called *tricars*.

Automobilist: The driver or user of an automobile.

Auto Truck: A motor-driven vehicle for transporting heavy loads; a heavy commercial car.

Auxiliary Air Valve: Valve controlling the admission of air through the auxiliary air intake of a carbureter.

Auxiliary Air Intake: Opening through which additional air is admitted to the carbureter at high speeds.

Auxiliary Exhaust: Ports cut through cylinder walls to permit exhaust gases to be released from the cylinder when uncovered by the piston. These are sometimes used as an additional scavenging means for the regular exhaust valves.

Auxiliary Fuel Tank: See "Fuel Tank, Auxiliary".

Auxiliary Spark Gap: See "Spark Gap, Outside".

Axle: The spindle with which a wheel revolves or upon which it revolves.

Axle, Cambered: An axle whose ends are slanted downwards to camber the wheels.

Axle, Channel: An axle which is U-shaped in cross section.

Axle, Dead: Solid, fixed, stationary axle. An axle upon which the wheels revolve but which itself does not revolve.

Axle, Dropped: An axle in which the central portion is on a lower level than the ends.

Axle, Floating: A full-floating axle. A live axle in which the shafts support none of the car weight, but serve only to turn the wheels.

Axle, I-Beam: An axle whose cross section is in the shape of the letter I.

Axle, Live: An axle in which are comprised the driving shafts that carry the power of the motor to the driving wheels.

Axle, Semi-Floating: A live axle in which the driving shafts carry a part of the car weight as well as transmitting the driving torque.

Axle, Three-Quarters Floating: A live axle in which the shafts carry a part of the weight of the car, but less than that carried by the semi-floating axle. It is intermediated by a floating axle and the semi-floating axle.

Axle, Trussed: An axle in which downward bending is prevented by a truss.

Axle, Tubular: An axle formed of steel tubing. Usually applied to the front axles, but sometimes used in referring to tubular shafts of rear axles.

Axle Casing: That part of a live axle that encloses the driving shafts and differential and driving gears. Axle housing.

Axle Housing: See "Axle Casing".

Axle Shaft: The member transmitting the driving torque from the differential to the rear wheels.

B

Babbitt: A soft metal alloy used for lining the bearings of shafts.

Back-Firing: An explosion of the mixture in the intake manifold or carbureter caused by the communication of the flame of explosion in the cylinders. Usually due to too weak a mixture. Popping.

Back Kick: The reversal of direction of the starting, caused by back-firing.

Backlash: The play between a screw and nut or between the teeth of a pair of gear wheels.

Back Pressure: Pressure of the exhaust gases due to improper design or operation of the exhaust system.

Baffle Plate: A plate used to prevent too free movement of a liquid in the container. In a gas engine cylinder, a plate covering the lower end of the cylinder to prevent too much oil being splashed into it. The plate has a slot through which the connecting rod may work.

Balance Gear: See "Differential Gear".

Balancing of Gasoline Engines: Insuring the equilibrium of moving parts to reduce the vibration and shocks.

Ball-and-Socket Joint: A joint in which a ball is placed within a socket recessed to fit it, permitting free motion in any direction within limits.

Ball Bearing: A bearing in which the rotating shaft or axle is carried upon a number of small steel balls which are free to turn in annular paths, called *races*.

Balladeur Train: A French name for a sliding change-speed gear.

Barking: The sound made by the explosions caused by after-firing.

Base Bearing: See "Main Bearing".

Base Explosion: See "Crankcase Explosion".

Battery: A combination of primary or secondary cells, as dry cells or storage cells.

Battery, Dry: See "Dry Battery".

Battery, Storage: See "Accumulator".

Battery Acid: The electrolyte in a storage battery.

Battery-Charging Plug: Power terminals to which the leads of a storage battery may be connected for charging the battery.

Battery Gage: (1) Voltmeter or ammeter or voltammeter for testing the specific gravity of the electrolyte in a secondary battery.

Battery Syringe: A syringe used to draw out a part of the electrolyte or solution from a storage battery cell to test its density and specific gravity.

Baumè: A scale indicating the specific gravity or density of liquids and having degrees as units. Gasoline of a specific gravity of .735 has a gravity of 61 degrees Baumé.

Bearing: A support of a shaft upon which it may rotate.

Bearing, Annular Ball: A ball bearing consisting of two concentric rings, between which are steel balls.

Bearing, Ball: A bearing in which the rotating shaft and the stationary portion of the bearings are separated from sliding contact by steel balls. A steel collar fitted to the shaft rolls upon the balls, which in turn roll upon steel collar attached to the stationary portion of the bearing.

Bearing, Cup and Cone: A ball bearing in which the balls roll in a race, which is formed between a cone-shaped fixed collar and a cup-shaped shaft collar.

Bearing, Main: The bearing in which rotates the crankshaft of an engine.

Bearing, Plain: A bearing in which the rotating shaft is in sliding contact with the bearing supporting it.

Bearing, Radial: A bearing designed to resist loads from a direction at right angles to the axis of the shaft.

Bearing, Roller: A bearing in which the journal rests upon, and is surrounded by, hardened steel rollers which revolve in a channel or race surrounding the shaft.

Bearing, Thrust: A bearing designed to resist loads or pressures parallel with the axis of the shaft.

Bearing Cap: That portion of a plain bearing detachable from the stationary portion, and which holds the bearing bushing and shaft.

Bearing Surface: The projected area of a bearing in a perpendicular plane to the direction of pressure.

Beau de Rochas Cycle: The four-stroke cycle used in most internal-combustion engines. This cycle was proposed by M. Beau de Rochas and put into practical form by Dr. Otto. See "Four-Cycle".

Belt and Clutch Dressing: A composition to be applied to belts and clutches to prevent them from slipping.

Belt Drive: A method of transmitting power from the engine to the countershaft or jack shaft by means of belts.

Benzine: A petroleum product having a specific gravity between that of kerosene and gasoline. Its specific gravity is between 60 degrees and 65 degrees Baumé.

Benzol: A product of the distillation of coal tar. Coal tar benzine. Used as a rubber solvent and in Europe as a motor fuel.

Berline Body: A limousine automobile body having more than two seats in the back part.

Bevel-Gear: Gears the faces of whose teeth are not parallel with the shaft, but are on a beveled edge of the gear wheel.

Bevel-Gear Drive: Method of driving one shaft from another at an angle to the first. The chief method of transmitting the drive from the propeller shaft to the rear axle shafts.

B. H. P.: An abbreviation for brake horsepower.

Bicycle: A two-wheeled vehicle propelled by the pedaling of the rider.

Binding Posts: See "Terminals".

Bleeder: A by-pass in the sight-feed of a mechanical oiling system by which the oil delivered through that feed is allowed to pass out instead of going to the bearings.

Blister: A defect in tires caused by the separation of the tread from the fabric.

Block Chain: A chain used in automobiles, bicycles, etc., of which each alternate link is a steel block.

Blow-Back: The backward rushing of the fuel gas through the inlet valve into the carbureter.

Blower Cooled: A gas engine cooled by positive circulation of air maintained by a blower.

Blow-Off: A blow-out caused by the edge of the bead of tire becoming free from the rim and allowing the tube to protrude through the space thus formed.

Blow-Out: The rupture of both the inner tube and outer casing of a pneumatic tire.

Blow-Out Patch: See "Patch, Tire Repair".

Body: (1) The superstructure of an automobile; the part that resembles and represents the body of a horse-drawn vehicle. (2) In oils, the degree of viscosity. The tendency of drops of oils to hang together.

Body Hangers: Attachments to or extensions of the frame for holding the body of the vehicle. They should be properly called frame hangers.

Boiler: A vessel in which water is evaporated into steam for the generation of power.

Boiler, Fire-Tube: A tubular steam boiler in which the end plates are connected by a number of open ended thin tubes, the spaces around which are filled with water, the hot gases passing through the tubes.

Boiler, Flash: A steam boiler in which steam is generated practically instantaneously. There is practically no water or steam stored in the boiler. A flash generator.

Boiler, Water-Tube: A steam boiler in which the water is carried in metal tubes, around which the hot gases circulate.

Boiler Alarm: See "Low-Water Alarm".

Boiler Covering: A non-conducting substance used as a covering for boilers to prevent loss of heat by radiation.

Boiler-Feed Pump: An automatic and self-regulating pump for supplying a boiler with feed water.

Boiler-Feed Regulator: A device to make the feed-water supply of the boiler automatic.

Bonnet: (1) The hood or metallic cover over the front end of an automobile. See "Hood". (2) The cover over a pump-valve box, or a slide-valve casing. (3) A cover to enclose and guide the tail end of a

steam-engine-valve spindle or the cover of a piston-valve casing. (4) The pan underneath the engine in an automobile.

Boot: A covering to protect joints from dirt and water or to prevent the leakage of grease. (2) Space provided for baggage at the rear of a car.

Bore: The inside diameter of the cylinder.

Boss: An enlarged portion of a part to give a point for attachment of another part.

Bottom: The meshing of gears without clearance.

Bow Separator: A part to prevent chafing of the bows of a top when folded.

Boyle's Law of Gases: A law defining the volume and pressure of gases at constantly maintained temperatures. It states that the volume of a gas varies inversely as the pressure so long as the temperature remains the same; or, the pressure of a gas is proportional to its density.

Brake: An apparatus for the absorption of power by friction, and by clamping some portion of the driving mechanism to retard or stop the forward motion of the car.

Brake, Air-Cooled: A brake whose parts are ridged to present a large surface for transferring to the air the frictional heat generated in them.

Brake, Band: A brake which contracts upon the outside of a drum attached to some part of the driving mechanism.

Brake, Constricting Band: A form of brake applied by tightening a band around a pulley or drum.

Brake, Differential: A brake acting upon the differential gear.

Brake, Double-Acting: A brake which will hold when the drum is rotating in either direction.

Brake, Drum, and Band: See "Brake, Band".

Brake, Emergency: A brake intended to be used in case the service brake does not act to a sufficient extent.

Brake, Expanding-Band: A drum brake in which the braking force is exerted by a band forced outward against the inner rim of a pulley.

Brake, External-Contracting: A brake consisting of a drum affixed to a rotating part, the outer surface of which is encircled by a contracting band.

Brake, Foot: A brake designed to be operated by the driver's foot. A pedal brake. Usually the service brake.

Brake, Front-Wheel: A brake designed to operate on the front wheels of the car.

Brake, Gearset: A brake designed to act on the transmission shaft and attached to the gearbox.

Brake, Hand: A brake designed to be operated by means of a hand lever. Usually the emergency brake.

Brake, Hub: A brake consisting of a drum secured to one of the wheels. This is the usual type.

Brake, Internal: A brake in which an expanding mechanism is contained within a rotating drum, the expansion bringing pressure to bear on the drum.

Brake, Internal-Expanding: A brake consisting of a drum, against the inside of which may be expanded a band or a shoe.

Brake, Motor: A brake in an electric vehicle which acts upon the armature shaft of the motor.

Brake, Service: A brake designed to be used in ordinary driving. It is usually operated by the driver's foot.

Brake, Shoe: A brake in which a metal shoe is clamped against a revolving wheel.

Brake, Transmission: A brake designed to act upon the transmission shaft.

Brake, Water-Cooled: A brake through which water may be circulated to carry off the frictional heat.

Brake Equalizer: A mechanism applied to a system of brakes operated in pairs to assure that each brake shall be applied with equal force.

Brake, Horsepower: The horsepower supplied by an engine as shown by the application of a brake or absorption dynamometer.

Brake Housing: A casing enclosing the brake mechanism.

Brake Lever: The lever by which the brake is applied to the wheel.

Brake Lining: The wearing surface of a brake; usually arranged to be easily replaced when worn.

Brake Pedal: Pedal by which the brake is applied.

Brake Pull Rod: A rod transmitting the tension from the lever or pedal to the movable portion of the brake proper.

Brake Ratchet: A device by which the brake lever or brake pedal can be set in position and retained there; usually consists of a notched quadrant with which a movable tongue on the lever head or pedal engages.

Brake Rod: The rod connecting the brake lever with the brake.

Brake Test: A test of a motor by means of a dynamometer to determine its power output at different speeds.

Braking Surface: The surface of contact between the rotating and stationary parts of a brake.

Braze: To join by brazing.

Brazing: The process of permanently joining metal parts by intense heat.

Breaker Strip: A strip of canvas placed between the tread and body of an outer tire casing to increase the wearing qualities.

Breather: An opening in the crankcase of a gas engine to permit pressure therein to remain equal during the movement of the pistons.

British Thermal Unit. The ordinary unit of heat. It is that quantity of heat required to raise the temperature of one pound of pure water one degree Fahrenheit at the temperature of greatest density of water.

Brougham Body: A closed-in automobile body having windows at the side doors, and in front, but with no extension of the roof over the front seat.

Brush Holder: In electrical machinery, an arrangement to hold one end of a connection flexible in contact with a moving part of the circuit.

B. T. U.: Abbreviation for *British Thermal Unit.*

Buckboard: A four-wheeled vehicle in which the body and springs are replaced by an elastic board or frame

Buckling: Irregularities in the shape of the plates of storage cells following a too rapid discharge.

Bumper: (1) A contrivance at the front of the car to minimize shock of collision; it consists of plungers working in tubes and gaining elasticity from springs. (2) A bar placed across the end of a car, usually the front end, to take the shock of collision and thus prevent damage to the car itself. A rubber or leather pad interposed between the axle and frame of a car.

Burner, "Torch" Igniter: A movable auxiliary vaporizer for starting the fire in steam automobile burners.

Bushing: A bearing lining. Usually made of anti-friction metal and capable of adjustment or renewal.

Bus-Pipe: A manifold pipe.

Butterfly Valve: A valve inserted in a pipe, usually circular and of nearly the same diameter as the pipe, designed to turn upon a spindle through its diameter and thus shut off or permit flow through the pipe. Usually employed for throttle valves and carbureter air valves.

Buzzer: (1) A name sometimes applied to the vibrator or trembler of a jump-spark ignition coil. (2) A device used in place of a horn, and consisting of a diaphragm which is made to vibrate rapidly by an electromagnet.

By-Pass: A small valve to provide a secondary passage for fluids passing through a system of piping.

C

C: Abbreviation for a centigrade degree of temperature.

Calcium Carbide: A compound of calcium and carbon used for the generation of acetylene by the application of water.

Calcium Chloride: A salt which dissolved in water is used as an anti-freezing solution.

Cam: A revolving disk, irregular in shape, fixed on a revolving shaft so as to impart to a rod or lever in contact with it an intermittent or variable motion.

Cam, Exhaust: A cam designed to operate the exhaust of an engine.

Cam, Ignition: A cam designed to operate the ignition mechanism. In magnetos it operates the make-and-break device.

Cam, Inlet: A cam designed to operate the inlet valve of an engine.

Camber: (1) The greatest depth of curvature of a surface. (2) The amount of bend in an axle designed to incline the wheels.

Camber of Spring: The maximum distance between the upper and lower parts of a spring under a given load.

Cambered Frame: A narrowing of the front of a motor car to permit of easier turning.

Cam Gear: The gear driving the camshaft of a gas engine. In a four-cycle engine this is the same as the two-speed gear.

Camshaft: A shaft by which the valve cams are rotated; also known as the *secondary shaft.*

Camshaft, Overhead: The camshaft carried along or above the cylinder heads, to operate overhead valves.

Camshaft Gears: The gears or train of gears by which the camshaft is driven from the crankshaft. Half-time gears, timing gears, distribution gears.

Canopy: An automobile top that can not be folded up.

Capacity of a Condenser: The quality of electricity or electrostatic charge. Of a storage battery, the amount of electricity which may be obtained by the discharge of a fully charged battery. Usually expressed in ampere hours.

Cape Hood: An automobile top which is capable of either being folded up or extended.

Car: A wheeled vehicle.

Carbide: See "Calcium Carbide".

Carbide Feed: A type of acetylene generator in which the calcium carbide is fed into the water.

Carbon Bridge: Formation of soot between points of spark plug.

Carbon Deposit: A deposit upon the interior of the combustion chamber of a gasoline engine composed of carbonaceous particles from the lubricating oil, too rich fuel mixture, or road dust.

Carbon Remover: A tool or solution for removing carbon deposits from the cylinder, piston, or spark plug of a gasoline engine.

Carbonization: The deposit of carbon.

Carbureter: An appliance for mixing an inflammable vapor with air. It allows air to be passed through or over a liquid fuel and to carry off a portion of its vapor mixed with the air, forming an explosive mixture.

Carbureter, Automatic: A carbureter so designed that either the air supply alone or both the air and gasoline supplies are regulated automatically.

Carbureter, Constant-Level: A carbureter the level of the gasoline in which is maintained automatically at a constant height. A float-feed carbureter.

Carbureter, Exhaust-Jacketed: A carbureter whose mixing chamber is heated by the circulation of exhaust gas.

Carbureter, Multiple-Jet: A carbureter having more that one spray nozzle or jet.

Carbureter, Water-Jacketed: A carbureter whose mixing chamber is heated by the circulation of water from the cooling system.

Carbureter Float: A buoyant part of the carbureter designed to float in the gasoline and connected to a valve controlling the flow from the fuel tank, designed to maintain automatically a constant level of the gasoline in the flow chamber.

Carbureter Float Chamber: A reservoir containing the float and in which a constant level of fuel is maintained.

Carbureter Jet: The opening through which liquid fuel is ejected in a spray from the standpipe of a carbureter nozzle.

Carbureter Needle Valve: A valve controlling the flow of fuel from the flow chamber to the standpipe.

Carbureter Nozzle: See "Carbureter Jet".

Carbureter Standpipe: A vertical pipe carrying the nozzle.

Carburetion: The process of mixing hydrocarbon particles with the air. The action in a carbureter.

Cardan Joint; A universal joint or Hooke's coupling.

Cardan Shaft: A shaft provided with a Cardan joint at each end.

Casing: The shoe or outer covering of a double-tube automobile tire.

Catalytic Ignition: See "Ignition,Catalytic".

Cell: One of the units of a voltaic battery.

Cell, Dry: See "Dry Cell".

Cell, Storage: See "Accumulator".

Cellular Radiator: A radiator in which the openings between the tubes are in the form of small cells. The same as a *honeycomb radiator*.

Cellular Tire: A cushion tire which is divided into compartments or cells.

Center of Gravity: That point in a body, which, if the body were suspended freely in equilibrium, would be the point of application of the resultant forces of gravity acting upon the body.

Center Control: The location of the gear-shift and emergency brake levers of a car in the center of a line parallel to the front of the front seat.

Centigrade Scale: The thermometer scale invented by Celsius. Used universally in scientific work.

Century. In automobiling, a hundred-mile run.

C. G. S. System: Abbreviation for centimeter-gram-second system of measurement; the standard system in scientific work.

Chain, Drive: A heavy chain by which the power from the motor may be transmitted to the rear wheels of an automobile.

Chain, Roller: A sprocket chain, the cross bars of whose links are rollers.

Chain, Silent: See "Silent Chain".

Chain, Tire: A small chain fastened about the tire to increase traction and prevent skidding.

Chain Wheel: A sprocket wheel for the transmission chains of a motor-driven vehicle.

Change-Speed Gear: See "Gear, Change-Speed".

Change-Speed Lever: See "Lever, Change-Speed".

Charge: The fuel mixture introduced into the cylinder of a gas engine. The act of storing up electric energy in an accumulator.

Charging: The passing of a current of electricity through a storage cell.

Charles' Law of Gases: See "Gases, Gay Lussac's Law of".

Chassis. The mechanical features of a motor car assembled, but without body, fenders, or other superstructure not essential to the operation of the car.

Chauffeur: In America this term means the paid driver or operator of a motor car. The literal translation from the French means stoker or fireman of a boiler.

Check, Steering: See "Steering Check".

Check Valve: An automatic or non-return valve used to control the admission of feed water in the boiler, etc.

Choke: The missing of explosions or poor explosions due to too rich mixture.

Circuit, Primary: See "Primary Circuit".

Circuit, Secondary: See "Secondary Circuit".

Circuit Breaker: A device installed in an electric circuit and intended to open the circuit automatically under predetermined conditions of current flow.

Circulating Pump: A pump which keeps a liquid flowing through a series of pipes which provides a return circuit. In a motor car. water and oil circulation is maintained by circulating pump.

Circulation Pump: A mechanically operated pump by which the circulation of water in the cooling system is maintained.

Circulating System: The method or series of pipes through which a continuous flow of water or oil is maintained and in which the liquid is sent through the system over and over.

Clash Gear: A sliding change-speed gear.

Clearance: (1) The distance between the road surface and the lowest part of the under-body of an automobile. (2) The space between the piston of an engine when at the extremity of its stroke, and the head of the cylinder.

Clearance, Valve: See "Valve Clearance".

Clearance Space: The space left between the end of the cylinder and the piston plus the volume of the ports between the valves and the cylinder.

Clevis: The fork on the end of a rod.

Clevis Pin: The pin passing through the ends of a clevis and through the rod to which the clevis is joined.

Clincher Rim: A wheel rim having a turned-in edge on each side, forming channels. Into this the edge or flange of the tire fits, the air pressure within locking the tire and rim together.

Clincher Tire: A pneumatic tire design to fit on a clincher rim.

Clutch: A device for engaging or disconnecting two pieces of shafting so that they revolve together or run free as desired.

Clutch Cone: A clutch whose engaging surfaces consist of the outer surface of the frustrum of one cone and the inner surface of the frustrum of another.

Clutch, Contracting-Band: A clutch consisting of a drum and band, the latter contracting upon the former.

Clutch, Dry-Plate: A clutch whose friction surfaces are metal plates, not lubricated.

Clutch, Expanding-Band: A clutch consisting of a drum and band, the latter expanding within the former.

Clutch, Jaw: A clutch whose members lock end to end by projections or jaws in one entering corresponding depressions in the other.

Clutch, Multiple-Disk: A clutch whose friction surfaces are metal plates or disks, alternate disks being attached to one member and the rest to the other member of the drive.

Clutch Brake: A device designed to stop automatically the rotation of the driven member of a clutch after disengagement from the driving member.

Clutch Lining: The wearing surface of a clutch. This may be easily removed and replaced when worn.

Clutch Pedal: The pedal by which the clutch may be disengaged, engagement being obtained automatically by means of a spring.

Clutch Spring: A spring arranged to either hold a clutch out of gear or throw it into gear.

Coasting: The movement of the car without constant applications of the motive power, as in running downhill with the aid of gravity or on the level, through the momentum obtained by previous power applications.

Cock, Priming: A small cock, usually operated by a lever, for admitting gasoline to the carbureter to start its action.

Coil, Induction: See "Spark Coil".

Coil, Non-Vibrator: A coil so designed that it will supply a sufficient spark for the ignition with one make and break of the primary circuit.

Coil, Primary: See "Primary Coil".

Coil, Secondary: See "Secondary Spark Coil".

Coil, Spark: See "Spark Coil".

Coil, Vibrator: A spark coil with which is incorporated an electromagnetic vibrator to make and break the primary circuit.

Coil Vaporizer: An auxiliary vaporizer to assist in starting a steam boiler. It is a coil of tubing into which liquid gasoline is admitted and burned to start the generation of gas in the main burner.

Cold Test: The temperature in degrees Fahrenheit at which a lubricant passes from the fluid to the solid state.

Combustion Chamber: That part of an explosive motor in which the gases are compressed and then fired, usually by an electric spark.

Combustion Space: See "Clearance" and "Clearance Space".

Commercial Car: A motor-driven vehicle for commercial use, such as transporting passengers or freight.

Commutator: In the ignition system of an explosive motor, the commutator is a device to automatically complete the circuit of each of a number of cylinders in succession.

Commutator of Dynamo or Motor: That part of a dynamo which is designed to cause the alternating current produced in the armature to flow in one direction in the external circuit; in a motor, to change the direct current in the external circuit into alternating current.

Compensating Carbureter: An automatic attachment to a carbureter controlling either air or fuel admission, or both, so that the proportion of one to the other is always maintained under any vibration of power required.

Compensating Gear: See "Differential Gear".

Compensating Joint: See "Universal Joint".

Compound Engine: A multiple-expansion steam engine in which the steam is expanded in two stages, first in the high-pressure cylinder and then in the low-pressure cylinder.

Compression: (1) That part of the cycle of a gas engine in which the charge is compressed before ignition; in a steam engine it is the phase of the cycle in which the pressure is increased, due to compression of the exhaust steam behind the piston. (2) The greatest pressure exerted on the gas in the compression chamber.

Compression Chamber: The clearance volume above the piston in a gas engine; also called "Compression Space".

Compression Cock: See "Compression-Relief Cock".

Compression Line: The line on an indicator diagram corresponding to the phase of the cycle in which the gas is compressed.

Compression-Relief Cock: A small cock by which the compression chamber of an internal-combustion motor may be opened to the air and thus allow the compression in the cylinder to be relieved to facilitate turning by hand, or *cranking*.

Compression Space: See "Compression Chamber".

Compression Tester: A small pressure gage by which the degree of compression of the mixture in a gas-engine cylinder may be tested.

Compressor, Air: See "Air Compressor".

Condenser: (1) In a steam motor, an apparatus in which the exhaust steam is converted back into water. (2) A device for increasing the electric capacity of a circuit. Used in an ignition circuit to increase the strength of the spark.

Cone Bearing: A shaft bearing in which the shaft is turned to a taper and the journal turned to a conical or taper form.

Cone Clutch: A friction clutch in which there are two cones, one fitting within the other.

Connecting Rods: The part of an engine connecting the piston to the crank, and by means of which a reciprocating motion of the piston is converted into the rotary motion of the crank.

Constricting Band Brake: See "Brake, Constricting Band".

Constricting Clutch: A friction clutch in which a band is tightened around a drum to engage it.

Contact Breaker: A device on some forms of gasoline motors having an induction coil of the single jump-spark type, to open and close the electric circuit of the battery and coil at the proper time for the passage of the arc or spark at the points of the spark plug.

Contact Maker: See "Contact Breaker".

Continental Drive: Double-chain drive.

Control: The levers, pedals, etc., in general with the speed and direction of a car is regulated by the driver. In speaking of right, left, or center control, the gearshift and emergency brake levers only are meant.

Control, Spark: Method of controlling the power of an engine by varying the point in the stroke at which ignition takes place.

Control, Throttle: Method of governing the power of the engine by altering the area of the passage leading to the admission valve so that the amount of the fuel introduced into the cylinder is varied.

Controller, Electric: Apparatus for securing various combinations of storage cells and of motors so as to vary the speed of the car at will.

Converter: A device for changing alternating current into direct current for charging storage batteries, etc. Converters may be any of three kinds: rotary, electrolytic, or mercury-vapor. The mercury-vapor converter is most widely used.

Convertible Body: An automobile body which may be used in two or more ways, usually as an open or closed carriage, or in which several seats may be concealed, and raised to increase the seating capacity.

Cooling Fan: Fan used in automobiles to increase the current of air circulating around the cylinders, or through the radiator.

Cooling System: The parts of a gas engine or motor car by which the heat is generated in the cylinder by the combustion of the fuel mixture. See "Water Cooling" and "Air Cooling".

Cork Inserts: Pieces of cork inserted in friction surfaces of clutches or brakes to give softer action.

Cotter Pin: A split metal pin designed to pass through holes in a bolt and nut to hold the former in place.

Coulomb: The unit of measure of electrical quantity. Sometimes called "Ampere Second". It is equivalent to the product of the current in amperes by the number of seconds current has been flowing.

Counterbalance: Weights attached to a moving part to balance that part.

Countershaft: An intermediate or secondary shaft in the power-transmission system.

Coupé: An enclosed body seating one or two passengers and the driver, all within.

Coupling, Flexible: See "Universal Joint".

Cowl: That portion of the body of the car which forms a hood over the instrument board or dash.

Cowl Tank: A fuel tank carried under the cowl and immediately in front of the dash.

Crank: A lever designed to convert reciprocating motion into rotating motion or *vice versa;* usually in the form of a lever formed at an angle with the shaft, and connected with piston by means of connecting rod.

Crank, Starting: A handle made to fit the projecting end of the crankshaft of a gas engine, so that the engine may be started revolving by hand.

Crankcase: The casing surrounding the crank end of the engine.

Crankcase Explosion: Explosion of unburned gases in the crankcase.

Crank Chamber: The enclosed space of small engines in which the crank works.

Cranking: The act of rotating the motor by means of a handle in order to start it. Turning the flywheel over a few times causes the engine to take up its cycle, and after an explosion it continues to operate.

Crankpin: The pin by which the connecting rod is attached to the crank.

Crankshaft: The main shaft of an engine.

Crankshaft, Offset: A crankshaft whose center line is not in the same plane as the axis of its cylinders.

Creeping of Pneumatic Tires: The tendency of pneumatic tires to push forward from the ground, and thus around the rim, in the effort to relieve and distribute the pressure.

Cross Member: A structural member of the frame uniting the side members.

Crypto Gear: See "Planetary Gear".

Crystallization. The rearrangement of the molecules of metal into a crystalline form under continued shocks. This is often the cause of the breaking of the axles and springs of a motor car.

Cup, Priming: A small cup-shaped device provided with a cock, by which a small quantity of gasoline can be introduced into the cylinder of a gasoline engine.

Current: The rate of flow of electricity; the quantity of electricity which passes per second through a conductor or circuit.

Current Breaker: See "Contact Breaker".

Current Indicator: A device to indicate the direction of current flow in a circuit; a polarity indicator.

Current Rectifier: A device for converting alternating current into direct current. See "Converter".

Cushion Tire: See "Tire, Cushion".

Cut-Off, Gas Engine: That point in the cycle of an internal-combustion engine at which the admission of the mixture is discontinued by the closing of the admission valve.

Cut-Off, Steam Engine: That point in the cyle of a steam engine, or that point on an indicator diagram, at which the admission of steam is discontinued by the closing of the admission valve.

Cut-Out, Automatic: A device in a battery charging circuit designed to disconnect the battery from the circuit when the current is not of the proper voltage.

Cut-Out, Muffler: A device by which the engine is made to exhaust into the air instead of into the muffler.

Cut-Out Pedal: Pedal by means of which the engine is made to exhaust into the air instead of into the muffler.

Cycle: A complete series of operations beginning with the drawing in of the working gas, and ending after the discharge of the spent gas.

Cycle, Beau de Rochas: See "Beau de Rochas Cycle".

Cylinder: A part of a reciprocating engine consisting of a cylindrical chamber in which a gas is allowed to expand and move a piston connected to a crank.

Cylinder Bore: See "Bore".

Cylinder Cock: A small cock used to allow the condensed water to be drained away from the cylinder of a steam engine, usually called a *drain cock.*

Cylinder Head: That portion of a cylinder which closes one end.

Cylinder Jacket: See "Jacket, Water".

Cylinder Oil: Lubricant particularly adapted to the lubrication of cylinder walls and pistons of engines.

D

Dash: The upright partition of a car in front of the front seat and just behind the bonnet.

Dash Adjustment: Connections by which a motor auxiliary may be adjusted by a handle on the dash. Usually applied to carbureter adjustments.

Dash Coil: An induction coil for jump-spark ignition, having an element for each cylinder, with dash connections to the commutator on the engine or camshaft.

Dash Gage: A steam, water, oil, or electric gage placed upon the dash of the car.

Day Type of Engine: The two-cycle internal-combustion engine with an air-tight crankcase.

Dead Axle: See "Axle, Dead".

Dead Center: The position of the crank and connecting rod in which they are in the same straight line. There are two positions, and in these positions no rotation of the crankshaft is caused by pressure on the piston.

Decarbonizer: See "Carbon Remover".

Deflate: Reduction of pressure of air in a pneumatic tire.

Deflector: In a two-cycle engine, the curved plate on the piston head designed to cause the incoming charge to force out the exhaust gases and thus assist in scavenging.

Deflocculated Graphite: Graphite so finely divided that it remains in suspension in a liquid.

Demountable Rim: A rim upon which a spare tire may be mounted and carried, and so arranged that it may be easily and quickly taken off or put on the wheel.

Denatured Alcohol: See "Alcohol, Denatured".

Densimeter: See "Hydrometer".

Depolarizer: Material surrounding the negative element of a primary cell to absorb the gas which would otherwise cause polarizing.

Detachable Body: A body which may be detached from and placed upon the chassis.

Detachable Rim: See "Demountable Rim".

Diagram Indicator: See "Indicator Card".

Diagram, Jeantaud: A diagrammatic representation of the running gear of an automobile, showing it turning corners of various radii for the purpose of determining the front-axle and steering connections.

Diesel Gas Engine: Four-cycle internal-combustion engine in which the explosion of the charge is accomplished entirely by the temperature produced by the high compression of the mixture.

Differential, Bevel-Gear: A balance gear in which the equalizing action is obtained by means of bevel gears.

Differential, Spur-Gear: A differential gear in which the equalizing action is obtained by spur gears.

Differential Brake: See "Brake, Differential".

Differential Case: See "Differential Housing".

Differential Gear: A mechanism to permit driving the wheels and yet allow them to turn a corner without slipping. An arrangement such that the driving wheels may turn independently of each other on a divided axle, both wheels being under the control of the driving mechanism. Sometimes called *balance*, *compensating*, or *equalizing gear*.

Differential Housing: The case that encloses the differential gear.

Differential Lock: A device which prevents the operation of the differential gear, so that the wheels turn as if they were on a solid shaft.

Dimmer: An arrangement for lowering the intensity of, or reducing the glare from headlights.

Direct Current: A current which does not change its direction of flow, as the current from a battery or a direct-current generator. Distinguished from an alternating current, which reverses its direction many times a minute.

Direct Drive: Transmission of power from engine to the final driving mechanism at crankshaft speed.

Discharge: In a storage battery, the passage of a current of electricity stored therein. In the ignition circuit, the flow of high-tension current at the spark gap.

Disk Clutch: A clutch in which the power is transmitted by a number of thin plates pressed face to face.

Distance Rod: See "Radius Rod".

Distribution Shaft: See "Camshaft".

Distributor: That part of the ignition system which directs the high-tension current, to the respective spark plugs in the proper firing order.

Double Ignition: A method of ignition which comprises two separate systems, either of which may be used independently of the other, or both together as desired. Usually distinguished by two current sources and two sets of plugs.

Drag: That action of a clutch or brake which does not completely release.

Drag Link: That rod in a steering gear which forms the connection between the mechanism mounted on the frame and the axle stub, and transmits the movements of steering from steering post to wheels.

Drive Shaft: The shaft transmitting the motion from the change gears to the driving axle; the torsion rod.

Driving Axle: The axle of a motor car through which the power is transmitted to the wheels.

Driving Wheel: The wheel to which or by which the motion is transmitted.

Dry Battery: A battery of one or more dry cells.

Dry Cell: A primary voltaic cell in which a moist material is used in place of the ordinary fluid electrolyte.

Dual Ignition: An ignition system comprising two sources of current and one set of spark plugs.

Dust Cap: A metal cap to be screwed over a tire valve to protect the latter from dust and water.

Dynamo: The name frequently applied to a dynamo-electric machine used as a generator. Strictly, the term *dynamo* should be applied to both motor and generator.

Dynamometer: The form of equalizing gear attached to a source of power or a piece of machinery to ascertain the power necessary to operate the machinery at a given rate of speed and under a given load.

E

Earth: See "Ground".

Economizer, Gas: An appliance to be attached to a float-feed carbureter to improve the mixture by automatically governing the amount of air in the float chamber.

Eccentric: A disk mounted off-center on a shaft to convert rotary into reciprocating motion.

Economy, Fuel: The fuel economy of a motor is the relation between the heat units

in the fuel used in the motor and the work or energy given out by the motor.

Efficiency: The proportion of power obtained from a mechanism as compared with that put into it.

Efficiency of a Motor: The efficiency of a gasoline motor is the relation between the heat units consumed by the motor and the work of energy in foot-pounds given out by it. Electrical efficiency of a motor is the relation between the electrical energy put into the motor and the mechanical energy given out by it.

Ejector: An apparatus by which a jet of steam propels a stream of water in almost the same way as an injector, except that the ejector delivers it into a vessel having but little pressure in it.

Electric Generator: A dynamo-electric machine in which mechanical energy is transformed into electrical energy; usually called *dynamo*.

Electric Horn: An automobile horn electrically operated.

Electric Motor: A dynamo-electric machine in which electrical energy is transformed into mechanical energy.

Electric Vehicle: An automobile propelled by an electric motor, for which current is supplied by a storage battery carried in the vehicle.

Electrolyte: A compound which can be decomposed by electric current. In referring to storage batteries, the term electrolyte means the solution of sulphuric acid in water in which the positive and negative plates are immersed.

Electromagnet: A temporary magnet which obtains its magnetic properties by the action of an electric current around it and which is a magnet only as long as such current is flowing.

Electromotive Force: A tendency to cause a current of electricity to flow; usually synonymous with *potential, difference of potential, voltage*, etc.

Element: The dissimilar substances in a battery between which an electromotive force is set up, as the plates of a storage battery.

Emergency Brake: A brake to be applied when a quick stop is necessary; usually operated by a pedal or lever.

En Bloc: That method of casting the cylinders of a gasoline engine in which all the cylinders are made as a single casting. Block casting; monoblock casting.

End Play: Motion of a shaft along its axis.

Engine, Alcohol: An internal-combustion engine in which a mixture of alcohol and air is used as fuel.

Engine, Gasoline: An internal-combustion motor in which a mixture of gasoline and air is used as fuel.

Engine, Kerosene: An internal-combustion engine in which a mixture of kerosene and air is used as fuel.

Engine, Steam: An engine in which the energy in steam is used to do work by moving the piston in a cylinder.

Engine Primer: A small pump to force fuel into the carbureter.

Engine Starter: An apparatus by which a gasoline engine may be started in its cycle of operations without use of the starting crank. It belongs usually to one of four classes: (1) Mechanical or spring actuated, such as a coil spring wound up by the running of the engine or a strap around the flywheel; (2) fluid pressure, such as compressed air or exhaust gases induced into the cylinder to drive the piston through one cycle; (3) the electric system, in which a small motor is used to turn the engine over; (4) combinations of these.

Epicyclic Gear: See "Planetary Gear".

Equalizing Gear: See "Differential Gear".

Exhaust: The gases emitted from a cylinder after they have expanded and given up their energy to the piston; the emission of the exhaust gases.

Exhaust, Auxiliary: See "Auxiliary Exhaust".

Exhaust Horn: An automobile horn in which the sound is produced by the exhaust gases.

Exhaust Lap: The extension of the inside edges of a slide valve to give earlier closing of the exhaust. Also called *inside lap*.

Exhaust Manifold: A large pipe into which the exhaust passages from all the cylinders open.

Exhaust Port: The opening through which the exhaust gases are permitted to escape from the cylinder.

Exhaust Steam: Steam which has given up its energy in the cylinder and is allowed to escape.

Exhaust Stroke: The stroke of an internal-combustion motor during which the burned gases are expelled from the cylinder.

Exhaust Valve: A valve in the cylinder of an engine through which the exhaust gases are expelled.

Expanding Clutch: A clutch in which a split pulley is expanded to press on the inner circumference of a ring which surrounds it, and thus transmits motion to the ring.

Expansion, Gas Engine: That part of the cycle of a gas engine immediately after ignition, in which the gas expands and drives the piston forward.

Expansion, Steam Engine: That portion of the stroke of the steam engine in which the steam is cut off by the valves and continues to perform work on the piston, increasing in volume and decreasing in pressure.

Explosive Motor: See "Internal-Combustion Motor".

F

Fan, Cooling: A mechanically operated fan for producing a current of air for cooling the radiator or cylinder of a gas engine.

Fan, Radiator: A mechanically operated rotary fan used to induce the flow of air through the radiator to facilitate the cooling of the water.

Fan Belt: The belt which drives the cooling fan.

Fan Pulley: A pulley permanently attached to the fan and over which the fan belt runs to drive it.

Fat Spark: A short, thick, ignition spark.

Feed Pump: A pump by which water is delivered from the tank to the boiler of a steam car.

Feed Regulator: A device to maintain a uniform water level in a steam boiler by controlling the speed of the feed pump.

Feed-Water Heater: An apparatus for heating the boiler-feed water, either by means of a jet of steam or steam-heated coils.

Fender: A mud guard or shield over the wheels of a car.

Field, Magnetic: Space in the neighborhood of the poles of a magnet in which the magnetism exerts influence. Field also refers to the coils which produce the magnetism in an electromagnet.

Fierce Clutch: A clutch which cannot be engaged easily. A grabbing clutch.

Filler Board: Woodwork shaped to fill the space between the lower edge of the windshield and the dash.

Fin: Projections cast on the cylinders of a gas engine to assist in cooling.

Final Drive: That part of a car by which the driving effort is transmitted from the parts of the transmission carried on the frame to the transmission parts on the rear axle. The propeller shaft in a shaft-drive car.

Fire Test: A test of a lubricant to determine the temperature at which it will burn.

Firing: (1) Ignition of the charge in a gas engine. (2) The act of furnishing fuel under the boiler of a steam engine.

First Speed: That combination of transmission gears which gives the lowest gear ration forward. Slow speed; low speed.

Flash Boiler: A boiler arranged to generate highly superheated steam almost instantaneously, by allowing water to come in contact with very hot metal surfaces.

Flash Generator: See "Flash Boiler".

Flash Point: The temperature at which an oil will give off a vapor that will ignite when a flame comes in contact with it.

Flash Test: A test to determine the flash point of oils.

Flexibility: In an engine the ability to do useful work through a range of speeds.

Flexible Coupling: See "Universal Joint".

Flexible Shaft: A pliant shaft which will transmit considerable power when revolving.

Flexible Tubing: A tube for the conduction of liquids or gases, which may be bent at a small radius without leaking.

Float Carbureter: A carbureter for gasoline engines in which a float of cork or hollow metal controls the height of the liquid in the atomizing nozzle. Sometimes called *float-feed carbureter*.

Float Valve: An automatic valve by which the admission of a liquid into a tank is controlled through a lever attached to a hollow sphere which floats on the surface of the liquid and opens or closes the valve according as it is high or low.

Floating Axle: See "Axle, Floating".

Floating the Battery on the Line: Charging the battery while it is giving out current.

Flooding: Excessive escape of fuel in a carbureter from the spraying nozzle.

Flushing Pin: In a float-feed carbureter, a pin arranged to depress the float in priming. Also called *primer* and *tickler*.

Flywheel: A wheel upon the shaft of an engine which, by virtue of its moving mass, stores up the energy of the gas transmitted to the flywheel during the impulse stroke and delivers it during the rest of the cycle, thus producing a fairly constant torque.

Flywheel Marking: Marks on the face of a flywheel to indicate the time of valve opening and closing and thus assist in valve setting.

Foaming: See "Priming".

Fore Carriage: A self-propelled vehicle in which the motor is carried on the forward trucks, and propelling and steering is done with the forward trucks.

Fore-Door Body: An automobile body having doors in the forward compartment.

Four-Cycle or Four-Stroke Cycle: The cycle of operations in gas engines occupying two complete revolutions or four strokes.

Four-Wheel Drive: Transmission of driving effort to all four wheels.

Fourth Speed: That combination of transmission gears which gives the fourth from the lowest gear ratio forward. Usually the highest speed.

Frame: The main structural part of a chassis. It is carried upon the axles by the springs and carries the different elements of the car.

Frame Hangers: See "Body Hangers".

Free Wheel: A wheel so arranged that it can rotate more rapidly than the mechanism which drives it.

Friction: The resistance existing between two bodies in contact which tends to prevent their motion on each other.

Friction Clutch: A device for coupling and disengaging two pieces of shafting while in motion, by the friction of cones or plates on one another.

Friction Disk: The thin plate used in a disk or friction clutch. See "Disk Clutch".

Friction Drive: A method of transmitting power or motion by frictional contact.

Fuel: A combustible substance by whose combustion power is produced. Gasoline and kerosene are the chief automobile fuels.

Fuel Economy. See "Economy, Fuel".

Fuel Feed, Gravity: See "Gravity Fuel Feed".

Fuel Feed, Pressure: See "Lubrication, Force-Feed."

Fuel Feed, Vacuum. See "Vacuum Fuel Feed".

Fuel-Feed Regulator: A device in the fuel system of steam motor by which the rate of flow of fuel to the burner is automatically regulated.

Fuel Level: The height of the top of the fuel in the float chamber of a carbureter.

Fuel-Level Indicator: An instrument either permanently connected to the fuel tank or which may be inserted thereon to indicate the quantity of fuel in the tank.

Fuel Tank, Auxiliary: A tank designed to hold a supply of fuel in addition to that carried in the main shaft.

Fuse: A length of wire in an electric circuit designed to melt and open the circuit when excess current flows through it and thus prevent damage to other portions of the circuit.

Fusible Plug: A hollow plug filled with an alloy which melts at a point slightly above the temperature of the steam in a boiler, as when the water runs low, thus putting out the fire and preventing the burning out of the boiler.

G

Gage: (1) Strictly speaking, a measure of, or instrument for determining dimensions or capacity. Practically, the term refers to an instrument for indicating the pressure or level of liquids, etc. (2) The distance between the forward or rear wheels measured at the points of contact of the tires on the road. Tread; track.

Gage Cock: A small cock by which a pipe leading to a gage may be opened or closed.

Gage Lamp: Lamp, usually electric, placed above or near the gages to enable them to be read at night.

Gage, Oil: See "Oil Gage".

Gage, Tire: See "Tire-Pressure Gage".

Gap: In automobiles, the spark gap.

Garage: A building for storing and caring for automobiles.

Garage, Portable: A garage which may be moved from one place to another either as a whole or in sections.

Gas: Matter in a fluid form which is elastic and has a tendency to expand indefinitely with reduction in pressure.

Gas Economizer: See "Economizer".

Gas Engine: An internal-combustion motor in which a mixture of gas and air is used as fuel. The term is also applied to the gasoline engine.

Gas Engine, Otto: A four-stroke cycle engine developed by Otto and using the hot-tube method of ignition.

Gas Generator: An apparatus in which a gas is generated for any use.

Gas Lamp: See "Acetylene Lamp".

Gases, Boyle's Law of: See "Boyle's Law of Gases".

Gases, Gay Lussac's Law of: Called *Charles's Law* and the *Second Law of Gases.* Law defining the physical properties of gases at constantly maintained pressure. It states that at constant pressure the volume of gas varies with the temperature, the increase being in proportion to the change of temperature and volume of the gas.

Gasket: A thin sheet of packing material or metal used in making joints, piping, etc.

Gasoline: A highly volatile fluid petroleum distillate; a mixture of fluid hydrocarbons.

Gasoline-Electric Transmission: A system of propulsion in which a gasoline engine drives an electric generator, and the power is transmitted electrically to motors which drive the wheels.

Gasoline Engine: An internal-combustion motor in which a mixture of gasoline and air is used as a fuel.

Gasoline Primer: The valve on the carbureter of a gasoline engine by which the action of the engine can be started.

Gasoline-Tank Gage: A fuel-lever indicator for gasoline.

Gasoline Tester: A hydrometer graduated to indicate the specific gravity of gasoline, usually in degrees Baumé.

Gate: A plate which guides the gearshift lever in making speed changes.

Gather: Convergence of the forward portions of the front wheels. Toeing in.

Gay Lussac's Law of Gases: See "Gases, Gay Lussac's Law of".

Gear, Balance: See "Differential Gear".

Gear, Bevel: See "Bevel Gear".

Gear, Change-Speed: An arrangement of gear wheels which transmits the power of the motor to the differential gear at variable speeds independently of the motor speed.

Gear, Differential: See "Differential".

Gear, Fiber: A gear cut from a vulcanized fiber blank.

Gear, Helical: A gear whose teeth are not parallel to the axis of the cylinders.

Gear, Internal: A gear whose teeth project inward toward the center from the circumference of gear wheel.

Gear, Planetary: See "Planetary Gears".

Gear, Progressive: See "Progressive Change-Speed Gears".

Gear, Rawhide: A gear cut from a blank made up of compressed rawhide.

Gear, Selective: See "Selective Change-Speed Gears".

Gear, Timing: See "Timing Gears".

Gear, Worm: A helical gear designed for transmitting motion at angles, usually at right angles and with a comparatively great speed reduction.

Gearbox: The case covering the change-speed gears.

Gear Shifting: Varying the speed ration between motor and rear wheels by operating the change-speed gears.

Gear-Shift Lever: A lever by which the change-speed gears are shifted.

Geared-Up Speed: A speed obtained by an arrangement of gears in the gearset such that the propeller shaft rotates more rapidly than the crankshaft.

Gearset: See "Gear, Change-Speed".

Generator, Acetylene: See "Acetylene Generator".

Generator, Electric: See "Electric Generator".

Generator, Steam: A steam boiler.

Generator Tubing: Tubing by which acetylene is conducted from the generator to the lamp.

Gimbal Joint: A form of universal joint.

Gong: A loud, clear sounding bell, usually operated either electrically or by foot power.

Governor: A device for automatically regulating the speed of an engine.

Governor, Dynamo: A method of automatic control of the generator (usually an ignition generator, in automobile work) by which its speed is maintained approximately constant.

Governor, Hydraulic: A governor applied to engines cooled by a pump circulation of water in such a way that the throttle opening is controlled by the pressure of the water.

Governor, Spark: A method of automatically controlling the speed of the engine by varying the time of ignition. See "Governor".

Grabbing Clutch: See "Fierce Clutch".

Gradometer: An instrument for indicating the degree of the gradient or the per cent of the grade. It consists of a level with a graduated scale.

Graphite: One of the forms in which carbon occurs in matter. Also known as *black lead*

and *plumbago*. Used as a lubricant in powdered or flake form in the cylinders of explosive engines.

Gravity-Feed Oiling System: See "Lubrication, Gravity".

Gravity Fuel Feed: Supply of fuel to the carbureter from the tank by force of gravity.

Grease and Oil Gun: A syringe by means of which grease or oil may be introduced into the bearings of the machinery.

Grease Cup: A device designed to feed grease to a bearing by the compression of a hand screw.

Grid: A lead plate formed in the shape of a gridiron to sustain and act as a conductor of electricity for the active material in a storage battery.

Grinding Valves: See "Valve Grinding".

Gripping Clutch: See "Fierce Clutch".

Ground: An electric connection with the earth, or to the framework of a machine.

H

Half-Motion Shaft: See "Half-Time Shaft".

Half-Time Gear: See "Timing Gears".

Half-Time Shaft: The cam shaft of a four-cycle gas engine. It revolves at one-half the speed of the crankshaft.

Hammer Break: A make-and-break ignition system in which the spark is produced when the moving terminal strikes the stationary terminal like a hammer.

Header: A pipe from which two or more pipes branch. Manifold.

Heater, Automobile: A device for warming the interior of an automobile, usually electric, or by means of exhaust gases or jacket water.

High Gear: That combination of change-speed gears which gives the highest speed.

High-Tension Current: A current of high voltage, as the current induced in the secondary circuit of a spark coil.

High-Tension Ignition: Ignition by means of high-tension current.

High-Tension Magneto: A magneto which delivers high-tension current.

Honeycomb Radiator: A radiator consisting of many very thin tubes, giving it a cellular appearance.

Hood: (1) That part of the automobile body which covers the frame in front of the dash. The engine is usually under the hood. (2) The removable covering for the motor.

Hooke's Coupler: See "Universal Joint".

Horizontal Motor: A motor the center line of whose cylinder lies in a horizontal plane.

Horn, Automobile: A whistle or horn for giving warning of the approach of the automobile.

Horsepower: The rate of work or energy expended in a given time by a motor. One horsepower is the rate or energy expended in raising a weight of 550 pounds one foot in one second, or raising 33,000 pounds one foot in one minute.

Horsepower Brake: The power delivered at the flywheel of an internal combustion engine as ascertained by a brake test.

Horsepower, Rated: The calculated power which may be expected to be delivered by a motor. In America the term usually refers to the horsepower as calculated by the S.A.E. formula.

Hot-Air Intake: The pipe or opening conveying heated air to the carbureter.

Hot-Head Ignition: The method of igniting the charge in a gas-engine cylinder by maintaining the head of the combustion chamber at a high temperature from the internal heat of combustion, as in the Diesel engine.

Hot-Tube Ignition: An ignition device formerly used for gas engines in which a closed metal tube is heated red-hot by a Bunsen flame. When the compressed gases in the cylinder are allowed to come in contact with this, ignition takes place.

Housing: A metallic covering for moving parts.

H.P.: (1) Abbreviation for *horsepower*. (2) Abbreviation for *high pressure*.

Hub Cap: A metal cap placed over the outer end of a wheel hub.

Hydrocarbons: Chemical combinations of carbon and hydrogen in varied proportions, usually distillates of petroleum, such as gasoline, kerosene, etc.

Hydrometer: An instrument by which the specific gravity or density of liquids may be ascertained.

Hydrometer Scale, Baumè's: An arbitrary measure of specific gravity.

I

I-Beam: Sometimes called *I-Section*. A structural piece having a cross section resembling the letter I. I-Beam front axle.

Igniter: An insulated contact plug without sparking points, used in make-and-break ignition with low-tension magneto.

Igniter, High-Speed: An igniter having a short spark coil for high-speed engines.

Igniter, Jump-Spark: A system of ignition in which is used a current of high pressure, which will jump across a gap in the high-pressure circuit, causing a spark at the gap.

Igniter, Lead of: Amount by which the ignition is advanced. See "Advanced Ignition".

Igniter, Primary: The apparatus in a primary circuit for making and breaking the circuit.

Igniter Spring: A spring to quickly break the circuit of a primary igniter.

Ignition, Advancing: See "Advanced Ignition".

Ignition, Battery: A system which gets its supply of current from a storage battery or dry cells. This system usually consists of a battery, a step-up coil, and a distributor for sending the current to the different spark plugs.

Ignition, Catalytic: Method of ignition for explosive motors based on the property of some metals, particularly spongy platinum, of becoming incandescent when in contact with coal gas or carbonized air.

Ignition, Double: See "Double Ignition".

Ignition, Dual: See "Dual Ignition".

Ignition, Fixed: Ignition in which the spark occurs at a given point in the cycle and cannot be changed from that point at the will of the operator except by retiming the ignition system. Fixed spark.

Ignition, Generator: Ignition current which is furnished by a combination lighting generator and magneto. The generator is

fitted with an interrupter and distributor. Sometimes refers to system in which a generator charges a battery and the latter furnishes the ignition current in connection with a coil and distributor.

Ignition, High-Tension: Sometimes called jump-spark. Ignition which is effected by means of a high-tension or high-voltage current which is necessary to jump a gap in the spark plug.

Ignition, Hot-Head: See "Hot-Head Ignition".

Ignition, Jump-Spark: See "Ignition, High-Tension".

Ignition, Low-Tension: See "Ignition, Make-and-Break".

Ignition, Make-and-Break: A system in which the spark is produced by the breaking or interruption of a circuit, the break occurring in the combustion space of the cylinder. The current used is of low-voltage, hence the synonym, low-tension ignition.

Ignition, Magneto: Ignition produced by an electric generator, called a magneto, which is operated by the gas engine for which it furnishes current. Dynamo ignition. Generator ignition.

Ignition, Master Vibrator: A system which uses as many non-vibrator coils as there are cylinders, and one additional coil, called the master vibrator, for interrupting the primary circuit for all coils. The master vibrator also is used with vibrator coils in which the vibrators are short-circuited.

Ignition, Premature: Ignition occurring so far before the top dead center mark that the explosion occurs before the piston has reached upper dead center.

Ignition, Primary: An ignition system in which a low-tension current flows through a primary coil, the circuit being mechanically opened, allowing a high-tension spark to jump across the gap. See "Primary Coil".

Ignition, Retarding: Setting the spark of an internal-combustion motor so that the ignition will occur at a later part of the stroke.

Ignition, Self: Explosion of the combustible charge by heat other than that produced by the spark. Incandescent carbon will cause this. Motor overheating because of lack of water is another cause.

Ignition, Single: A system using but one source of current.

Ignition, Synchronized: Ignition by means of which the timing in each cylinder of a multicylinder engine is the same. In synchronized ignition the spark occurs at the same point in the cycle in each cylinder. This type of ignition is obtained with a magneto and is lacking in a multi-coil system using vibrator coils.

Ignition, Timing of: The adjustment of the ignition system so that ignition will take place at the desired part of the cycle.

Ignition, Two-Independent: See "Ignition, Double".

Ignition, Two-Point: A system comprising two ignition sources, or a double-distributor magneto, and two sets of spark plugs, both of which spark at the same time.

Ignition Distributor: See "Distributor."

Ignition Switch: A control or switch for turning the ignition current on and off voluntarily.

I. H. P.: Abbreviation for *indicated horsepower.*

Indicated Horsepower: (1) The horsepower developed by the fuel on the pistons, in contradistinction to brake horsepower. See "Horsepower, Brake". (2) The horsepower of an engine as ascertained from an indicator diagram.

Indicator: An instrument by which the working gas in an engine records its working pressure.

Indicator Card: A figure drawn by means of an indicator by the working gas in an engine. Also called *indicator diagram.*

Induction Stroke: The downstroke of a piston which causes a charge of mixture to be drawn into the cylinder.

Inflammation: The act or period of combustion of the mixture in the cylinder.

Inflate: To increase the pressure within a tire by forcing air into it.

Inflator, Mechanical Tire: A small power-driven air-pump for inflating the tire; either driven by gearing, chain, or belt from the engine shaft, or by friction from the flywheel.

Inherent Regulation: Expression applied to electric generators which use no outside means of regulating the output, the regulation being affected by various windings of the armature and fields.

Initial Air Inlet: See "Primary Air Inlet".

Initial Pressure: Pressure in a cylinder after the charge has been drawn in but not compressed.

Injector: A boiler-feeding device in which the momentum of a steam jet, directed by a series of conical nozzles, carries a stream of water into the boiler, the steam condensing within and heating the water which it forces along.

Inlet, Valve: The valve which controls the inlet port and so allows or prevents mixture from passing to the cylinder.

Inlet Port: Passage or entrance in the cylinder wall through which the fuel mixture is taken. Sometimes called intake port.

Inlet Manifold: Sometimes called intake manifold or header. A branched pipe connected to the mixing chamber at one end and at the branch ends to the cylinders so as to communicate with the inlet ports.

Inlet Manifold, Integral: A manifold or header cast integral with the cylinder.

Inner-Tire Shoe: A piece of leather or rubber placed within the tire to protect the inner tube.

Inner Tube: A soft air-tight tube of nearly pure rubber, which fits within a felloe upon the casing.

Inside Lap: See "Exhaust Lap".

Intake Manifold: The large pipe which supplies the smaller intake pipes from each cylinder of a gas engine.

Intake Pipe: Sometimes made synonymous with inlet manifold. Correctly, the pipe from the carbureter to the inlet manifold.

Intake Stroke: See "Induction Stroke".

Intensifier: See "Outside Spark Gap".

Intermediate Gear: A gear in a change-speed set between high and low. In a three-speed set it would be second speed. In a four, either second or third.

Intermediate Shaft: See "Shaft, Intermediate".

Internal-Combustion Motor: Any prime mover in which the energy is obtained by the combustion of the fuel within the cylinder.

Internal Gear: See "Gear, Internal".

Interrupter: See "Vibrator".

J

Jack: A mechanism by which a small force exerted over a comparatively large distance is enabled to raise a heavy body. Used for raising the automobile axle to remove the weight from the wheels.

Jacket, Water: A portion of the cylinder casting through which water flows to cool the cylinder.

Jacket Water: The cooling water circulating in a water-cooling system.

Jackshaft: Shaft used in double-chain drive vehicles. Shaft placed transversally in the frame and driving from its ends chains which turn the rear wheels mounted on a dead axle.

Jeantaud Diagram: See "Diagram, Jeantaud".

Joint Knuckle: See "Swivel Joint."

Joule's Law of Gases: See "Gases, Joule's Law of".

Jump Spark: A spark produced by a secondary jump-spark coil.

Jump Spark, Circuit Maker: A mechanically operated switch by which the circuit in a jump-spark ignition system is opened and closed.

Jump-Spark Coil: An electrical transformer and interrupter, consisting of a primary winding of a few turns of coarse wire surrounding an iron core, and a secondary winding consisting of a great number of turns of very fine wire. The condenser is usually combined with this. Also known as *secondary spark coil.*

Jump-Spark Igniter: See "Igniter, Jump-Spark".

Jump-Spark Plug: See "Spark Plug".

Junction Box: A portion of an electric-lighting system to which all wires are carried for the making of proper connections.

Junk Ring: A packing ring used in sleeve-valve motors. It has the same functions as a piston ring. See "Piston Ring".

K

Kerosene: A petroleum product having a specific gravity between 58° and 40° Baumé. It is used as a fuel in internal-combustion engines and can often be used in gasoline engines by starting the engine on gasoline, then switching to kerosene.

Kerosene Burner: A burner especially adapted to use kerosene as a fuel.

Kerosene Engine: An engine using kerosene as fuel.

Key: A semicircular or oblong piece of metal used to hold a member firmly on a revolving shaft so as to prevent the member from rotating.

Key, Baldwin: A key with an oblong section.

Key, Woodruff: A key with a semicircular section.

Keyway: Slot in a rotating member used to hold the key

Kick Switch: Ignition switch mounted so that the driver can operate it with the foot.

Kilowatt: An electrical unit equal to 1000 watts.

Knuckle Joint: See "Swivel Joint".

L

Labor: The jerky operation of an engine. The engine is said to labor when it cannot pull its load without misfiring or jerking.

Lag, Combustion: The time between the instant of the spark occurrence and the explosion.

Lag, Ignition: The time between the instant of spark occurrence and the time at which the spark mechanism producing it begins to act.

Lamp, Trouble: Sometimes called inspection lamp. A small electric bulb carried in a suitable housing, and attached to a long piece of lamp cord. Used for inspecting parts of the car.

Lamp Bulb: The incandescent bulb used in a lamp.

Lamp Bracket: A support for a lamp.

Lamp Lighter: An apparatus for lighting gas lamps by electricity. The lamps are usually so arranged that by pushing the button the gas is turned on and the spark made at the same time.

Landaulet: A type of car which may be used as an open or closed car. The rear portion of the body may be folded down like a top.

Landaulet Body: An automobile body resembling a limousine body, but having a cover fitted to the back, which may be let down, leaving the back open. The top generally extends over the driver.

Lap: To make parts fit perfectly by operating them with an abrasive, such as ground glass, between the rubbing surfaces. To finish.

Lap of Steam Valves: In the slide valve of a steam engine, the amount by which the admission edges overlap the steam port when the valve is central with the cylinder case.

Layshaft: A countershaft or secondary shaft of a gearset operated by the main or shifter shaft.

Lead, or Lead Wire: Any wire carrying electricity.

Lead: In a steam engine the amount by which the steam port is opened when the piston is at the start of its stroke.

Lead Battery: See "Accumulator".

Lead of Igniter: See "Igniter, Lead of".

Lead of Valve: In an engine the amount by which the admission port is opened when the piston is at the beginning of the stroke; according as this is greater or less, the admission of working fluid is varied through several fractions of the stroke.

Lean Mixture: Fuel after leaving the carbureter, which contains too much air in proportion to the gasoline. Sometimes called thin mixture, rare mixture, or weak mixture.

Lever, Brake: See "Brake Lever."

Lever, Change-Speed: Lever by which the different combinations of change gears are made so as to vary the speed of the driving

wheels in relation to the speed of the engine; also called gearshift lever.

Lever, Spark: Lever by which the speed and power of the engine are controlled by adjusting the time of ignition.

Lever, Steering: See "Steering Lever".

Lever, Throttle: A lever by which the speed and power of the engine are controlled by adjusting the amount of mixture admitted to the cylinder.

Lever Lock: An arrangement for locking the gearshift lever in free position so that with the engine running the driving axle will not be driven.

Lift: The distance through which a poppet valve is moved in opening from fully-closed to fully-open position.

Lifting Jack: See "Jack".

Lighting Outfit, Electric: An outfit for electrically lighting an automobile. This usually consists of a dynamo, storage battery, and lamps and switchboard, with the necessary wiring and cut-outs.

Limousine Body: An enclosed automobile body having the front and sides with side doors. The top extends over the seat of the driver.

Liner: One or more pieces of metal placed between two parts so they may be adjusted by varying the thickness of the liner. Sometimes called a shim. Also refers to a tool used for lining up parts.

Liner, Laminated: A liner or shim made in a number of parts, the thickness being varied by removing or adding parts.

Lines of Force: See "Field, Magnetic".

Link Motion: In a steam engine, the name for the arrangement of eccentric rods, links, hangers, and rocking shafts by which the relative motion and position of the slide valves are changed at will, providing for varying rates of expansion of the steam and thus varying the speed for either forward or backward motion.

Live Axle: See "Axle, Live".

Lock, Auto Safety: A device arranged so that it is impossible to start the motor car except by the proper combination or key.

Lock Nut: A nut placed on a bolt immediately behind the main nut to keep the main nut from turning.

Lock Switch: A switch in the ignition circuit so arranged that it can not be thrown on except by the use of a key.

Lock Valve: A valve capable of being secured with lock and key.

Long-Stroke: A gas engine whose stroke is considerably greater than its bore.

Lost Motion: Sometimes called play or backlash. Looseness of space between two moving parts.

Louver: A slit or opening in the side of a hood or bonnet of a motor car. Used to allow air from the draft to escape. A ventilator.

Low Gear: The lowest speed gear. First speed in a change-speed set.

Low-Speed Adjustment: A carbureter adjustment which regulates the mixture when the motor is operating slowly, with little throttling opening.

Low-Speed Band: The brake or friction band which controls the low speed of a planetary change-speed set.

Low-Tension Current: A current of low voltage or pressure, such as is generated by dry cells, storage battery, or low-tension magneto.

Low-Tension Ignition: See "Ignition, Make-and-Break".

Low-Tension Magneto: A magneto which initially generates a current of low voltage.

Low-Tension Winding: The winding of a transformer or induction coil through which the primary or low-tension current flows.

Low Test: Gasoline which has a high density, thus giving a low reading on the Baumé scale. Low-grade gasoline.

Low-Water Alarm: An automatic arrangement by which notice is given that the water in the boiler is becoming too low for safety.

Lubricant: An oil or grease used to diminish friction in the working parts of machinery.

Lubrication: To supply to moving parts and their bearings grease, oil, or other lubricant for the purpose of lessening friction.

Lubrication, Circulating: A system in which the same oil is used over and over.

Lubrication, Constant-Level: A system in which the level in the crankcase is kept to a predetermined level by means of a pump.

Lubrication, Force-Feed: Method of lubricating the moving parts of an engine by forcing the oil to the points of application by means of a pump.

Lubrication, Gravity: Method of supplying oil to moving parts of an engine by having a reservoir at a certain height above the highest point to be lubricated and allowing the oil to flow to the points of application by gravity.

Lubrication, Non-Circulating: A system in which the same oil is used but once.

Lubrication, Pressure-Feed: See "Lubrication, Force-Feed".

Lubrication, Sight-Feed: System of lubrication in which the oil pipe to different points of application is led through a glass tube in plain sight; usually at a point on the dashboard.

Lubrication, Splash: Method of lubricating an engine by feeding oil to the crankcase and allowing the lower edge of the connecting rod to splash into it.

Lubricator: A device containing and supplying oil or grease in regular amounts to the working parts of the machine.

Lubricator, Force-Feed: A pump-like device which automatically forces oil to the moving parts.

M

Magnet: A piece of iron or steel which has the characteristic properties of being able to attract other pieces of iron and steel.

Magnet, Horseshoe: A magnet shaped like the letter U.

Magnet, Permanent: A magnet which when once charged retains its magnetism.

Magnetic Field: See "Field, Magnetic".

Magnetic Spark Plug: A spark plug used in a make-and-break system of ignition in which contact is obtained by means of a magnet.

Magneto: See "Ignition, Magneto".

Magneto: See "Magneto-Electric Generator".

Magneto, Double-Distributor: A magneto with two distributors feeding two sets of spark plugs, two in each cylinder and both sparking at once. See "Ignition, Two-Point."

Magneto, High-Tension: A magneto has two armature windings and requires no outside coil for the generation of high-tension current.

Magneto, Induction: A type of magneto in which the armature and fields are stationary and a rotator or spool-shaped piece of metal is used to break the lines of force.

Magneto, Low-Tension: See "Low-Tension Magneto".

Magneto, Rotating Armature: A magneto in which the armature winding revolves.

Magneto Bracket: A shelf or portion of the crankcase web used to support the magneto.

Magneto Coupling: A flexible joint which connects the magneto with a revolving motor shaft.

Magneto Distributor: See "Distributor".

Magneto-Electric Generator: A machine in which there are no field magnet coils, the magnetic field of the machine being due to the action of permanent steel magnets. Usually contracted to *magneto*.

Main Bearing: A bearing used for supporting the crankshaft.

Manifold: A main pipe or chamber into which or from which a number of smaller pipes lead to other chambers. See "Intake Manifold", "Exhaust Manifold", and "Inlet Manifold".

Manometer: A device for indicating either the velocity or the pressure of the water in the coiling system of a gasoline motor.

Master Vibrator: A single vibrator which interrupts the current to each of a set of several spark coils in order.

Mean Effective Pressure: The average pressure exerted upon a piston throughout its stroke.

M. E. P.: Abbreviation for *mean effective pressure*.

Mercury Arc Rectifier: A mercury vapor converter. See "Mercury Vapor Converter".

Mercury Vapor Converter: An apparatus for converting alternating current into direct current by means of a bubble of mercury in a vacuum. The vapor of mercury possesses the property of allowing the flow of current in one direction only. Its principal use is for charging storage batteries.

Mesh: Two gears whose teeth are so positioned that one gear will drive the other are said to be in mesh.

Misfire: Failure of the mixture to ignite in the cylinder; usually due to poor ignition or poor mixtures.

Miss: The failure of a gas engine to explode in one or more cylinders. Sometimes called misfiring.

Mixing Chamber: A pipe or chamber placed between the carbureter and inlet manifold. Sometimes integral with the carbureter or manifold.

Mixing Tube: A tubular carbureter for a gas or gasoline engine.

Mixing Valve: A device through which air and gas are admitted to form an explosive mixture. The carbureter of a gasoline engine combines the mixing valve and vaporizer.

Mixture: The fuel of a gas engine, consisting of sprayed gasoline mixed with air.

Monobloc: Cast *en bloc* or in one piece. Refers usually to cylinders, which are cast two or more at once.

Motocycle: A trade name for a special make of motorcycle.

Motor, Electric: See "Electric Motor".

Motor, Gasoline: See "Gasoline Motor".

Motor, High-Speed: A gas engine whose rotative speed is very high and whose power output goes up with the speed to an unusual degree.

Motor, Horizontal: A gas engine whose cylinder axis lies in a horizontal plane.

Motor, I-head: A gas engine which has cylinders, a section of which resembles the letter I. This type has the valves in the head.

Motor, L-Head: A gas engine in which a section of cylinders resembles the letter L. The valves in this type are all on one side.

Motor, Long-Stroke: See "Long-Stroke Motor".

Motor, Non-Poppet: A gas engine whose valves are not of the poppet type. In this class is the Knight sleeve valve, the rotary valve, and the piston valve.

Motor, Overhead Valve: A motor with cylinders whose valves are in the head.

Motor, Piston Valve: A gas engine using valves which are in the form of pistons.

Motor, Poppet: A gas engine using poppet-type valves. See "Poppet Valve".

Motor, Revolving Cylinder: A motor whose cylinders revolve as a unit.

Motor, Rotary Valve: One in which the valves consist of slots cut out along cylindrical rods which rotate in the cylinder casting.

Motor, Sliding Sleeve: The Knight type motor in which thin sleeves slide up and down in the cylinder, the sleeves having ports which register with the inlet and exhaust manifolds.

Motor, T-Head: A gas engine with the valves on opposite sides of the cylinders, a section of which resembles the letter T.

Motor, V-Type: A motor whose cylinders are set on the crankcase so as to form an angle of 45 to 90 degrees between them.

Motor, Vertical: A motor with the cylinder axis in a vertical plane.

Motorcycle: A bicycle propelled by a gasoline engine.

Mud Guard: Metal or leather strips placed over the wheels to catch the flying mud and to prevent the clothing from coming in contact with the wheels when entering and leaving the car.

Muffler Cut-Out: See "Cut-Out, Muffler".

Muffler Cut-Out Pedal: See "Cut-Out Pedal".

Muffler Exhaust: A vessel containing partitions, usually perforated with small holes and designed to reduce the noise occasioned by the exhaust gases of an engine, by forcing the gases to expand gradually.

Muffler Explosion: Explosion of unburned gases in exhaust passages of the muffler, usually due to poor ignition or poor mixture.

Multiple Circuit: A compound circuit in which a number of separate sources or electrically operated devices, or both, have all their positive poles connected to a single positive conductor and all their negative poles to a single negative conductor.

N

N.A.A.M.: Abbreviation for National Association of Automobile Manufacturers.

Naphtha: A product of the distillation of petroleum used to some extent for marine engines.

Needle Valve: A valve in a carbureter used for regulating the amount of gasoline to flow in with the mixture.

Negative Plate: Plate of a storage battery to which current returns from the outside circuit.

Negative Pole: That pole of an electric source through which the current is assumed to enter or flow back into the source after having passed through the circuit external to the source.

Neutral Position: The position of the change-speed lever which so places the gears that the motor may run idle, the car remaining still.

Non-Deflatable Tire: See "Tire, Non-Puncturable".

Non-Freezing Solution: A solution placed into the radiator of a motor car to prevent the water therein from freezing. Alcohol and glycerine are the usual anti-freezing agents. See "Anti-Freezing Solution".

Non-Puncturable Tire: See "Tire, Non-Puncturable".

Non-Skid Device: See "Anti-Skid Device".

O

Odometer: (1) The mileage-recording mechanism of a speedometer. (2) An instrument to be attached to an automobile wheel to automatically indicate the distance traveled.

Odometer, Hub: A speed-recording device which is placed on the hub cap of a wheel.

Offset: Off center, as a crankshaft in which a line vertically through the crankpins does not coincide with a line vertically through the center of the cylinder.

Ohm: (1) Unit of electrical resistance. (2) Amount of electrical resistance. Such resistance as would limit the flow of electricity under an electromotive force of one volt to a current of one ampere.

Ohm's Law: The law which gives the relation between voltage, resistance, and current flow in any circuit. Expressed algebraically, $C=\frac{I}{R}$ where C is the current flowing in amperes, I the voltage and R the ohmic resistance.

Oil Burner: A burner equipped with an atomizer for breaking up liquid fuel into a spray.

Oil Engine: An internal-combustion motor using kerosene or other oil as fuel.

Oil Gage: (1) A gage to indicate the flow of oil in the lubricating system. (2) Used to show the level of oil in a compartment in the base of a gas engine.

Oil Gun: A cylinder with a long point and a spring plunger for squirting oil or grease into inaccessible parts of a machine.

Oil Pump: A small force pump providing a constant positive supply of oil under pressure; usually considered to be more reliable than a lubricator.

Oiler: An automobile device for oiling machinery.

Opposed Motor: A gasoline engine whose cylinders are arranged in pairs on opposite sides of the crankshaft, both connecting rods of each pair being connected to the same crank, so that the shock of the explosion in one will be balanced by the cushioning effect of the compression in the other. In general these motors are two-cylinder, horizontal.

Otto Cycle: See "Four-Stroke Cycle".

Outside Spark Gap: See "Spark Gap, Outside".

Overcharged: The state of the storage battery when it has been charged at too high a rate or for too great a length of time.

Overhead Camshaft: A camshaft which is placed above the cylinder of a gas engine.

Overhead Valves: See "Motor, Overhead Valve".

Overheating: The act of allowing the motor to reach an excessively high temperature due to the heat of combustion being not carried away rapidly enough by the cooling devices, or to insufficient lubrication. Overheating of a bearing is due to insufficient lubrication.

P

Packing: The material introduced between the parts of couplings, joints, or valves, to prevent the leakage of gas or liquids to or from them.

Panel, Charging: A small switchboard for charging a storage battery.

Parallel Circuit: See "Multiple Circuit".

Patch, Tire-Repair: Rubber strips for making repairs in punctured or ruptured tires.

Petcock: A control cock which when open allows gas or liquid to escape from the chamber to which it is attached.

Petrol: Word used in England for gasoline.

Picric Acid: Acid which may be added to gasoline to increase the motor efficiency. Gasoline will absorb about five per cent of its weight of picric acid.

Pin, Taper: A conically shaped pin.

Pinch: A cut in an inner tube caused by the tube being caught or pinched between the outer casing and the rim.

Pinion: (1) The smaller of any pair of gears. (2) A small gear made to run with a larger gear.

Piston: The hollow, cylindrical portion attached to the connecting rod of a motor. The reciprocating part which takes the strain caused by the explosion.

Piston Air Valve: A secondary air valve in the piston of earlier types of gas engines to compensate the imperfect operation of surface carbureters used with those engines and to secure the injection of a sufficient quantity of air to insure the combustion of the charge.

Piston Head: The top of the piston.

Piston Pin: A pin which holds the connecting rod to the piston.

Piston Ring: (1) A metal ring inserted in a groove cut into a piston assisting in making the latter tight in the cylinder. There are usually three rings on each piston. (2) Rings about the circumference of a piston, whose diameter is slightly greater than that of the piston. These are to insure closer fit and prevent wearing of the piston, as the wear is taken up by the rings which may be easily removed.

Piston Rod: Usually called connecting rod. The rod which connects the piston with the crankshaft.

Piston Skirt: The portion of a piston below the piston pin.

Piston Speed: The rate at which the piston travels in its cylinder.

Piston Stroke: The complete distance a piston travels in its cylinder.

Pitted: Condition of a working surface which has become covered with carbon particles which have been imbedded in the metal.

Planetary Gear: An arrangement of spur and annular gears in which the smaller gears revolve around the main shaft as planets revolve around the sun.

Planetary Transmission: A transmission system in which the speed changes are obtained by a set of planetary gears.

Plate: Part of a storage battery which holds active material. See "Negative Plate".

Pneumatic Tire: A tire fitted to the wheels of automobiles, consisting usually of two tubes, the outer of India rubber, canvas, and other resilient wear-resisting material, and the inner composed of nearly pure rubber which is inflated with compressed air to maintain the outer tube in its proper form under load.

Polarizing: Formation of gas at the negative element of a cell so as to prevent the action of the battery. This formation of gas is caused by the violent reaction taking place in a circuit of low resistance.

Pole Piece: A piece of iron attached to the pole of a magneto used in an electric generator.

Poppet Valve: A disk or drop valve usually seating itself through gravitation or by means of springs, and frequently opening by suction or cams.

Port: An opening for the passage of the working fluid in an engine.

Portable Garage: See "Garage, Portable".

Positive Connection: A connection by which positive motion is transmitted by means of a crank, bolt, or key, or other method by which shipping is eliminated.

Positive Motion: Motion transmitted by cranks or other methods in which slipping is eliminated.

Positive Plate: Plate in a storage battery, from which the current flows to the outside circuit.

Positive Pole: The source from which electricity is assumed to flow; the opposite of negative pole. In a magnet the positive pole is the end of the magnet from which the magnetic flux is assumed to emanate.

Pounding in Engine: Pounding noise at each revolution, usually caused by either carbon deposit, loose or tight piston, loose bearing or other part, or pre-ignition.

Power Stroke: The piston stroke in a gas engine in which the exploded gases are expanding, thus pushing the piston downward.

Power Tire Pump: A pump which is operated by a gas engine and is used to inflate the tires of a motor car.

Power Unit: The engine with fuel, cooling, lubrication, and ignition systems, without the transmission or running gears. Sometimes the gearset and driving shaft are included by the term.

Pre-Ignition: See "Premature Ignition".

Premature Ignition: Ignition of fuel before the proper point in the cycle.

Pressure-Feed: See "Lubrication, Force-Feed".

Pressure Gage: A gage for indicating the pressure of a fluid confined in a chamber, such as steam in a boiler, etc.

Pressure Lubricator: A lubricating device in which the oil is forced to the bearings by means of a pump or other device for maintaining pressure.

Pressure Regulator: A device for maintaining the pressure of the steam in the principal pipe at a constant point irrespective of the fluctuations of pressure in the boiler.

Primary Air Inlet: The main or fixed air intake of a carbureter.

Primary Circuit: The circuit which carries low-tension current.

Primary Coil: A self-induction coil consisting of several turns of wire about an iron core.

Primary Spark Coil: An induction coil which has only a single winding composed of a few layers of insulated copper wire wound on a bundle of soft iron wires, known as the *core*, also as a *wipe*, or *touch*, *spark coil*.

Primer: A pin in a float-feed valve so arranged that it may depress the float in priming a gasoline engine. Also called *tickler* and *flushing pin*.

Priming: (1) The carrying of water over with the steam from the boiler to the engine, due to dirty water, irregular evaporation, or forced steaming. (2) Injecting a small amount of gasoline into the cylinder of a gasoline engine to assist in starting.

Priming Cock: A control cock screwed into the cylinder and which when open communicates with the combustion chamber allowing gasoline to be poured into the cylinder.

Progressive Change-Speed Gears: Change-speed gears so arranged that higher speeds are obtained by passing through all the intermediate steps and *vice versa*.

Prony Brake: A dynamometer to indicate the horsepower of an engine. A band encircles the flywheel of the engine and is secured to a lever, at the other end of which is a scale to measure the pull.

Propeller Shaft: The shaft which turns the rear axle of a motor car. The drive shaft.

Pump, Centrifugal: A pump with a hollow hub and curved blades which by centrifugal force throw water or oil into the system requiring it.

Pump, Circulation: See "Circulation Pump".

Pump, Fuel-Feed: A mechanically operated pump for insuring positive feed of fuel to the burner of a steam engine or carbureter of a gas engine.

Pump, Oil: See "Oil Pump".

Pump, Plunger: Sometimes called piston pump. One containing a piston which forces a liquid to a system.

Pump, Power Tire: See "Tire Pump".

Pump, Steam Boiler-Feed: See "Boiler-Feed Pump".

Pump, Water Circulating: See "Circulation Pump".

Pump Gear: A pump composed of two gears in mesh placed in a housing. When the gears revolve they carry oil or water, as the case may be, on their teeth, which deliver it to an outlet.

Puncture: The perforation of an inflated rubber automobile tire by some sharp substance on the roadbed.

Puncture-Closing Compound: A viscous compound placed within the inner tire tube to close the hole caused by a puncture.

Push Rod: A rod which operates the valves of a poppet-valve motor. A rod which imparts a pushing motion.

R

Race: (1) The parts upon which the balls of a ball bearing roll. (2) When referring to a gas engine, to operate at high speed without a load.

Racing Body: A low, light automobile body, having two seats with backs as low as possible; designed for large fuel capacity and very high speed.

Radiator: A device consisting of a large number of small tubes, through which the heated water from the jacket of the engine passes to be cooled, the heat being carried away from the metal of the radiator by air.

Radiator, Cellular: See "Honeycomb Radiator".

Radiator, Tubular: A radiator consisting of many tubes, through which water passes to be cooled.

Radiator Protector: See "Bumper".

Radius Rod: A bar in the frame of an automobile to assist in maintaining the proper distance between centers. Also called *distance rod*.

Rawhide Gear: Tooth gears, built up of compressed rawhide, used for high-speed drive. Sometimes a metal gear is merely faced with rawhide for the purpose of reducing noise.

Reach Rod: See "Radius Rod".

Reciprocating Parts: The parts such as pistons and connecting rods which have a reciprocating motion.

Rectifier, Alternating-Current: See "Current Rectifier".

Relief Cock: See "Compression-Relief Cock".

Removable Rim: See "Demountable Rim".

Resiliency: That property of a materia by virtue of which it springs back or recoils on removal of pressure, as a spring.

Resistance, Electrical: (1) A part of an electric circuit for the purpose of opposing the flow of the current in the circuit. (2) The electrical resistance of a conductor is that quality of a conductor by virtue of which the conductor opposes the passage of electricity through its mass. Its unit is the *ohm*.

Retard: With reference to the ignition system, causing the spark to occur while the piston is retarding or moving downward on the working stroke.

Retarding Ignition: See "Ignition, Retarding".

Retarding the Spark: See "Ignition, Retarding".

Retread: To replace the tread of a pneumatic tire with a new one.

Reverse Cam: On a gasoline engine a cam so arranged that by reversing its motion or shifting it along its shaft it will operate the valves and cause the engine to reverse.

Reverse Gear: In a steam engine, a device by which the valves may be set to effect motion of the car in either direction. In a gasoline automobile, the reversing gear is usually incorporated with the change-speed gears.

Reverse Lever: A lever by which the direction of movement of the driving wheels may be reversed without reversing the engine. This is usually combined with the change-speed levers.

Rheostat: A device for regulating the flow of current in a closed electrical circuit by introducing a series of graduated resistances into the circuit.

Rim: The portion of a wheel to which a solid or pneumatic tire is fitted. A circular, channel-shaped portion attached to the wheel felloe.

Rim, Demountable: A rim which may be removed from the wheel easily in order that another with an inflated tire may take its place.

Rim, Quick-Detachable: A rim made of two or more parts so that the tire may be detached and attached quickly.

Rim, Removable: See "Demountable Rim".

Road Map: A map of a section or locality showing the best roads for motor-car travel, and usually the best stopping places and repair stations.

Roadster: A small motor car designed to be fairly speedy; usually has carrying capacity for an extra large quantity of fuel and supplies; generally seats two persons, with provision for one or two more, by the attachment of a rumble seat in the rear.

Rocker Arm: A pivoted lever used to operate overhead valves in a T-head motor.

Rod, Radius: See "Radius Rod".

Rod, Steering: See "Steering Rod".

Roller Bearings: See "Bearing, Roller".

Roller Chain: A chain whose links are provided with small rollers to decrease the friction and the noise.

Rotary Valve: A type of valve somewhat similar to the Corliss engine valve used on automobile motors.

Rumble: A small single seat to provide for an extra passenger on a two-seated vehicle. Usually detachable.

Runabout: A small two-seated vehicle, usually of a lower power and lower speed, as well as lower operating radius, than a roadster.

Running Board: A horizontal step placed below the frame and used to assist passengers in leaving and entering a motor car.

Running Gear: The frame, springs, motor, wheels, speed-change gears, axles, and machinery of an automobile, without the body; used synonymously with *chassis*.

S

Safety Plug: See "Fusible Plug".

Safety Valve: A valve seated on the top of a steam boiler, and loaded so that when the pressure of the steam exceeds a certain point the valve is lifted from the seat and allows the steam to escape.

Saturated Steam: The quality of the steam when no more steam can be made in the closed vessel without raising the temperature or lowering the pressure.

Scavenging: The action of clearing the cylinder of an internal-combustion motor of the burned-out gases.

Score: To burn, or abrade a moving part with another moving part.

Screw: An inclined plane wrapped around a cylinder; a cylinder having a helical groove cut in its surface.

Searchlight: A headlight designed to throw a very bright light on the road. Electricity or acetylene is usually used as an illuminant, and the lamp has a parabolic reflector and may be turned to throw the light in any direction.

Secondary Battery: See "Accumulator".

Secondary Circuit: A circuit in which the electromotive force is generated by induction from a primary circuit in which a variable current is flowing. The high-tension circuit of a jump-spark ignition system.

Secondary Circuit: The circuit which carries high-tension current.

Secondary Spark Coil: An induction coil having a double winding upon its core. The inner winding is composed of a few layers of insulated wire of large size, and the outer winding consists of a great many layers of very small insulated copper wire. Also known as a *jump-spark coil*.

Seize: Refers to moving parts which adhere because of operation without a film of oil between the working surfaces.

Selective Change-Speed Gears: Change-speed gears so arranged that any desired speed combination can be obtained without going through the intermediate steps.

Self-Firing: Ignition of the mixture in a gas engine due to the walls of the cylinder or particles attached to them becoming overheated and incandescent.

Self-Starter: See "Engine Starter".

Separator, Steam: A device attached to steam pipes to separate entrained water from live steam before it enters the engine, or to separate the oily particles from exhaust steam on its way to the condenser.

Series Circuit: A compound circuit in which the separate sources or the separate electrical receiving devices, or both, are so placed that the current supplied by each, or passed through each, passes successively through the other circuits from the first to the last.

Set Screw: A small screw with a pointed end used for locking a part in a fixed position to prevent it from turning.

Setting Valves: See "Valve Setting".

Shaft, Intermediate: The shaft placed between the first and third motion gearing and acting as a carrier of motion between the two.

Shaft Drive: System of power transmission by means of a shaft.

Shim: See "Liner".

Shock Absorber: A device attached to the springs or hangers of motor cars to decrease the jars due to rough roads, instead of allowing them to be transmitted to the frame of the carriage.

Short Circuit: A shunt or by-path of comparatively small resistance around a portion of an electric circuit, by which enough current passes through the new path to virtually cut out the part of the circuit around which it is passed, and prevent it from receiving any appreciable current.

Sight Feed: An indicator covered with glass which shows that oil is flowing in a system. A telltale sight. A check on the oiling system.

Side-Bar Steering: See "Steering, Side-Bar".

Side-Slipping: See "Skidding".

Silencer: See "Muffler, Exhaust".

Silent Chain: A form of driving chain in which the links are comprised of sections which so move over the sprocket that practically all noise is eliminated. Silent chains are used specially for driving timing gears, gearsets, etc.

Skidding: The tendency of the rear wheels to slide sideways to the direction of travel, owing to the slight adhesion between tires and the surface of the roadbed, also called *side-slipping*.

Skip: See "Miss".

Sleeve Valve: A form of valve consisting of cylindrical shells moving up and down in the cylinders of such a motor as the Silent Knight.

Sliding Gears: A change-speed set in which various gears are placed into mesh by the sliding on a shaft of one or more gears.

Sliding Sleeve: See "Motor, Sleeve-Valve".

Slip Cover: A fabric covering for the top when down or for the upholstery of a motor vehicle.

Smoke in Exhaust: Smoky appearance in the exhaust due to too much oil, too rich mixture, low grade of fuel, or faulty ignition.

Solid Tire: See "Tire, Solid".

Sooting of Spark Plug: Fouling of the spark plug with soot, due to poor mixture, impure fuel, or improper lubrication.

Spare Wheel: An extra wheel complete with inflated tire, carried on the car for quick replacement of wheel with damaged tire.

Spark, Advancing: See "Advanced Ignition".

Spark Coil: A coil or coils of wire for producing a spark at the spark plug. It may be either a secondary or primary spark coil.

Spark Gap: A break in the circuit of a jump-spark ignition system for producing a spark within the cylinder to ignite the charge. The spark gap is at the end of a small plug called the *spark plug*.

Spark Gap, Extra: See "Spark Gap, Outside".

Spark Gap, Outside: A device to overcome the short circuiting in the spark gap due to fouling and carbon deposits between the points of the high-tension spark plug. It is a form of condenser, or capacity in which the air acts as the dielectric between two surfaces at the terminals of a gap in a high-tension circuit.

Spark Intensifier: See "Spark Gap, Outside".

Spark Lever: See "Timing Lever".

Spark Plug: The terminals of the secondary circuit of a jump-spark ignition system mounted to leave a spark gap between the terminals projecting inside the cylinder for the purpose of igniting the fuel in the cylinder by means of a spark crossing the gap between them.

Spark Plug, Pocketing: Mounting the spark plug in a recess of the cylinder head to reduce the sooting of the sparking points.

Spark Plug, Sooting of: See "Sooting of Spark Plug".

Spark Regulator: A mechanism by which the time of ignition of the charge is varied by a small handle on or near the steering wheel.

Spark, Retarding: See "Ignition, Retarding".

Spark Timer: See "Timer, Ignition".

Speaking Tube: See "Annunciator".

Specific Gravity: The weight of a given substance relative to that of an equal bulk of some other substance which is taken as a standard of comparison. Air or hydrogen is the standard for gases, and water is the standard for liquids and solids.

Specific Heat: The capacity of a substance for removing heat as compared with that of another which is taken as a standard. The standard is generally water.

Speed-Change Gear: A device whereby the speed ratio of the engine and driving wheels of the car is varied.

Speed Indicator: An instrument for showing the velocity of the car.

Speedometer: A device used on motor cars for recording the miles traveled and for indicating the speed at all times.

Speedometer Gears: Gears used to drive a shaft which operates the speedometer.

Speedometer Shaft: A flexible shaft which operates a speedometer.

Spiral Gear: A gear with helically-cut teeth.

Splash Lubrication: See "Lubrication, Splash".

Spline: A key.

Spontaneous Ignition: See "Self-Firing".

Sprag: A device to be let down (usually at the rear of the car) to prevent its slipping back when climbing a hill.

Spray Nozzle: That portion of a carbureter which sprays the gasoline.

Spring: An elastic body, as a steel rod, plate, or coil, used to receive and impart power, regulate motion, or diminish concussion.

Spring, Cantilever: A type of spring which appears like a semi-elliptic reversed; and which is flexibly attached in the center, rigidly at one end, and by a shackle at the other.

Spring, Elliptic: A spring, elliptic in shape, and consisting of two half-elliptic members attached together.

Spring Semi-Elliptic: A spring made up of a number of leaves, the whole resembling a portion of an ellipse.

Spring, Supplementary: See "Shock Absorber".

Spring, Underslung: A spring which is fastened under the axle instead of over it.

Spring Hangers: See "Body Hangers".

Spring Shackle: A link attached to one end of a spring which allows for flattening of the spring.

Sprocket: A wheel with teeth around the circumference, so shaped that the teeth will fit into the links of a chain which drives or is driven by the sprocket.

Starboard: The right-hand side of a ship or vessel.

Starter, Engine: See "Engine Starter".

Starting, Gas Engine: The operation necessary to make the engine automatically continue its cycle of events. It usually consists of opening the throttle, retarding the spark, closing the ignition circuit, and cranking the engine.

Starting Crank: A crank by which the engine may be given several revolutions by hand in order to start it.

Starting Device: See "Engine Starter".

Starting on Spark: In engines having four or more cylinders with well-fitting pistons, it is often possible to start the motor after it has stood idle for some time by simply closing the ignition circuit, provided that the previous stopping of the engine was done by opening the ignition circuit before the throttle was closed, leaving an unexploded charge under compression in one of the cylinders.

Steam: The vapor of water; the hot invisible vapor given off by water at its boiling point.

Steam Boiler: See "Boiler".

Steam Condenser: See "Condenser".

Steam, Cycle of: A series of operations of steam forming a closed circuit, a fresh series beginning where another ends; that is, steam is generated in the boilers, passes through the pipes of the engine, doing work successively in its various cylinders, escaping at exhaust pressure to the condenser, where it is converted into water and returned to the boiler, to go through the same operations once more.

Steam Engine: A motor depending for its operation on the latent energy in steam.

Steam Gage: See "Pressure Gage".

Steam Port: See "Admission".

Steering, Side-Bar: Method of guiding the car by means of an upright bar at the side of the seat.

Steering Angle for Front Wheels: Maximum angle of front wheels to the axle when making a turn; should be about 35°.

Steering Check: A device for locking the steering gear so that the direction will not be changed unless desired.

Steering Column: See "Steering Post".

Steering Gear: The mechanism by which motion is communicated to the front axle of the vehicle, by which the wheels may be turned to guide the car as desired.

Steering Knuckle: A knuckle connecting the steering rods with the front axle of the motor.

Steering Lever: A lever or handle by which the car is guided.

Steering Neck: The vertical spindle carried by the steering yoke. It is the pivot of the bell crank by which the wheel is turned.

Steering Pillar: See "Steering Post".

Steering Post: The member through which the twist of the steering wheel is transmitted to the steering knuckle. The steering post often carries the spark and throttle levers also.

Steering Rod: The rod which connects the steering gear with the bell cranks or pivot arms, by means of which the motor car is guided.

Steering Wheel: The wheel by which the driver of a motor car guides it.

Steering Yoke: The Y-shaped piece in which the front axle terminates. The yoke carries the vertical steering spindle or steering neck.

Stephenson Link Motion: A reversing gear in which the ends of the two eccentric rods are connected by a link or quadrant sliding over a block at the end of the valve spindle.

Step-Up Coil: A coil used to transform low- into high-tension current.

Storage Battery: See "Accumulator".

Stroke: See "Piston Stroke".

Strainer, Gasoline: A wire netting for preventing impurities entering the gasoline feed system.

Strangle Tube: The narrowing of the throat of the carbureter just above the air inlets in order to increase the speed of the air, and thus increase the proportion of gas which will be picked up.

Stroke: The distance of travel of a piston from its point of farthest travel at one end of the cylinder to its point of farthest travel at the other end. Two strokes of the piston take place to every revolution of the crankshaft.

Stud Plate: The plate or frame in a planetary transmission system carrying studs upon which the central pinions revolve.

Suction Valve: The type of admission valve on an internal combustion engine which is opened by the suction of the piston within the cylinder and admits the mixture. The valve is normally held to its seat by a spring.

Sulphating of Battery: The formation of an inactive coating of lead sulphate on the surface of the plates of a storage battery. It is a source of loss in the battery.

Superheated Steam: Steam which has been still further heated after reaching the point of saturation.

Supplementary Air Valve: See "Auxiliary Air Valve".

Swivel Joint: The joint for connecting the steering arm of the wheel or lever-steering mechanism to the arms on the steering wheel. Also called *knuckle joint.*

T

Tachometer: An instrument for indicating the number of revolutions made by a machine in a unit of time.

Tandem Engine: A compound engine having two or more cylinders in a line, one behind the other, and with pistons attached to the same piston rod.

Tank Gage: See "Fuel-Level Indicator".

Tappet Rod: See "Push Rod".

Taxicab: A public motor-driven vehicle in which the fare is automatically registered by the taximeter.

Taximeter: An instrument in a public vehicle for mechanically indicating the fare charged.

Terminals: The connecting posts of electrical devices, as batteries or coils.

Thermal Unit: Usually called the *British Thermal Unit*, or *B. t. u.* A measure of mechanical work equal to the energy required to raise one pound of water one degree Fahrenheit.

Thermostat: An instrument to automatically regulate the temperature.

Thermosiphon Cooling: A method of cooling the cylinder of a gas engine. The water rises from the jackets and siphons into a radiator from whence it returns to the supply tank, doing away with the necessity for a circulating pump.

Three-Point Suspension: A method used for suspending motor car units, such as the motor, on three points.

Throttle: A valve placed in the admission pipe between the carbureter and the admission valve of the motor to control the speed and power of the motor by varying the supply of the mixture.

Throttle, Foot: See "Accelerator".

Throttle, Lever: A lever on the steering wheel which operates the carbureter throttle. See "Throttle".

Throttling: The act of closing the admission pipe of the engine so that the gas or steam is admitted to the cylinder less rapidly, thus cutting down the speed and power of the engine.

Thrust Bearing: A bearing which takes loads parallel with the axis of rotation of the shaft upon which it is fitted.

Tickler: A pin in a carbureter arranged to hold down the float in priming, also called *flushing pin* and *primer.*

Timer, Ignition: An ignition commutator.

Timing Gears: The gears which operate the camshaft and magneto shaft. The camshaft gear is twice as large as the crankshaft gear.

Timing Lever: A lever fitted to gas engines by means of which the time of ignition is changed. Also called *spark lever.*

Timing Valve: In a gas engine using float-tube ignition, a valve controlling the opening between the combustion space and the igniter.

Tip, Burner: A small earthen, aluminum, or platinum cover for the end of the burner tube of an acetylene lamp. It is usually provided with two holes, so placed that the jets from them meet and spread out in a fan shape.

Tire, Airless: See "Airless Tire".

Tire, Clincher: A type of pneumatic tire which is held to a clincher.

Tire, Cushion: Vehicle tire having a very thick rubber casing and very small air space. It is non-puncturable and does not have to be inflated, but is not as resilient as a pneumatic tire.

Tire, Non-Deflatable: See "Tire, Non-Puncturable".

Tire, Non Puncturable: A tire so constructed that it cannot be easily punctured or will not become deflated when punctured.

Tire, Punctures in: Holes or leaks in pneumatic tires caused by foreign substances penetrating the inner tube and allowing the air to escape.

Tire, Single-Tube: A pneumatic tire in which the inner and outer tubes are combined.

Tire, Solid: A tire made of solid, or nearly solid rubber.

Tire Band: A band to protect or repair a damaged pneumatic tire. See "Tire Protector".

Tire Bead: Lower edges of a pneumatic tire which grip the curved portion of a rim.

Tire Case: (1) A leather or metal case for carrying spare tire; same as *tire holder.* (2) The outer tube.

Tire Chain: See "Anti-Skid Device".

Tire Filling: Material to be introduced into the tire to take the place of air and do away with puncture troubles

Tire Gage: Gage used for measuring the air pressure in a pneumatic tire.

Tire Holder: A metal or leather case for carrying spare tires.

Tire-Inflating Tank: A tank containing compressed air or gas for inflating the tires.

Tire Inflater, Mechanical: A small mechanical pump for inflating pneumatic tires.

Tire Patch: See "Patch, Tire Repair".

Tire-Pressure Gage: A pressure gage to indicate the pressure of air in the tire.

Tire Protector: The sleeve or band placed over a tire to protect it from road wear.

Tire Pump: A pump for furnishing air under pressure to the tire, may be either hand- or power-operated.

Tire Sleeve: A sleeve to protect the injured part of a pneumatic tire. It is a tire protector which covers more of the circumference of the wheel than a tire band. See "Tire Protector".

Tire Tape: Adhesive tape used to bind the outer tube to the rim in repairing tires.

Tire Tool: Tool used to apply and remove a tire.

Tire Valve: A small valve in the inner tube to allow air to be pumped into the tube without permitting it to escape.

Tires, Creeping of: See "Creeping of Tires".

Tonneau: The rear seats of a motor car. Literally, the word means a round tank or water barrel.

Torque: Turning effort, or twisting effort of a rotating part.

Torque Rod: A rod attached at one end to the rear axle and at the other to the frame; used to prevent twisting of the rear-axle housing.

Torsion Rod: The shaft that transmits the turning impulse from the change gears to the rear axle. Usually spoken of as the *shaft.*

Touch Spark: See "Wipe Spark".

Tourabout: A light type of touring car.

Touring Car: A car with no removable rear seats, and a carrying capacity of four to seven persons.

Town Car: A car having the rear seats enclosed but the driver exposed.

Traction: The act of drawing or state of being drawn. The pull (or push) of wheels.

Tractor: A self propelled vehicle for hauling other vehicles or implements; a traction engine.

Transmission, Individual Clutch: A transmission consisting of a set of spur gears on parallel shafts which are always in mesh, different trains being picked up with a separate clutch for each set.

Transmission, Planetary: A transmission system in which a number of pinions revolve about a central pinion in a manner similar to the revolution of the planets about the sun; usual type consists of a central pinion surrounded by three or more pinions and an internal gear.

Transmission, Sliding Gear: A transmission system in which sliding change-speed gears are used.

Transmission Brake: Brake operating on the gearset shaft or end of the propeller shaft.

Transmission Gears: A set of gears by which power is transmitted. In automobiles, usually called *change-speed gears.*

Transmission Ratio: The ratio of the speed of the crankshaft to the speed of the transmission shaft or driving shaft.

Tread: That part of a wheel which comes in contact with the road.

Tread, Detachable: A tire covering to protect the outer tube, which may be taken off or replaced.

Trembler: The vibrating spring actuated by the induction coil magnet which rapidly connects and disconnects the primary circuit in connection with jump-spark ignition.

Truck: (1) A strong, comparatively slow-speed vehicle, designed for transporting heavy loads. (2) A swiveling carriage having small wheels, which may be placed under the wheels of a car.

Try Cock: A faucet or valve which may be opened by hand to ascertain the height of water in the boiler.

Tube Case: See "Tire Case".

Tube Ignition: See "Hot-Tube Ignition".

Tubing, Flexible: See "Flexible Tubing".

Tubular Radiator: An automobile radiator in which the jacket water circulates in a series of tubes.

Tungsten Lamp: Incandescent bulb with the filament made of tungsten wire.

Turning Moment: See "Torque".

Turning Radius: The radius of a circle which the wheels of a car describe in making its shortest turn.

Turntable: Device installed in the floor of a garage and used for turning motor cars around.

Two-Cycle or Two-Stroke Cycle Engine: An internal-combustion engine in which an impulse occurs at the beginning of every revolution, that is, at the beginning of every downward stroke of the piston.

Two-to-One Gear: The system of gearing in a four-cycle gas engine for driving the camshaft, which must revolve once to every two revolutions of the crankshaft.

U

Under Frame: The main frame of the chassis or running gear of a motor vehicle.

Unit-Power Plant: A power system consisting of a motor, gearset, and clutch which may be removed from the motor car as a unit.

Universal Joint: A mechanism for endwise connection of two shafts so that rotary motion may be transmitted when one shaft is at an angle with the other. Also called *universal coupling, flexible coupling, Cardan joint* and *Hooke's joint.*

Upkeep: The expenditure for maintenance or expenditure required to keep a vehicle in good condition and repair.

V

Vacuum Fuel Feed: A system of feeding the gasoline from a tank at the rear of an automobile by maintaining a partial vacuum at some point in the system, usually at the dash, the fuel flowing from this point by gravity to the carbureter.

Vacuum Line: In an indicator diagram, the line of absolute vacuum. It is at a distance corresponding to 14.7 pounds below the atmospheric line.

Valve: A device in a passage by which the flow of liquids or gases may be permitted or stopped.

Valve, Admission: The valve in the admission pipe of the engine leading from the carbureter to the cylinder by which the supply of fuel may be cut off.

Valve, Automatic: See "Automatic Valve".

Valve, Inlet: See "Inlet Valve".

Valve, Mixing: See "Mixing Valve".

Valve, Muffler Cut-Out: See "Cut-Out, Muffler".

Valve, Overhead: See "Overhead Valve".

Valve, Poppet: See "Poppet Valve".

Valve, Rotary: See "Motor, Rotary Valve".

Valve, Suction: An admission valve which is opened by the difference between the pressures in the atmosphere and in the cylinder.

Valve Cage: A valve-retaining pocket which is attached to the cylinder.

Valve Clearance: The clearance of play between the valve stem and the tappet.

Valve Gear: The mechanism by which the motion of the admission or exhaust valve is controlled.

Valve Grinding: The act of removing marks of corrosion, pitting, etc., from the seats and faces of poppet or disk valves. The surfaces to be ground are rotated in contact with each other, an abrasive having been supplied.

Valve Lift: See "Lift".

Valve Lifter: A device for raising a poppet valve from its seat.

Valve Seat: (1) That portion of the engine upon which the valve rests when it is closed. (2) The portion upon which the face of a valve is in contact when closed.

Valve Setting: The operation of adjusting the valves of an engine so that the events of the cycle occur at the proper time. Also called *valve timing.*

Valve Spring: The spring which is around the valve stem and is used to return the valve to closed position after it has been opened by the cam:

Valve Stem: The rod-like portion of a poppet valve.

Valve Timing: See "Valve Setting".

Vaporizer: A device to vaporize the fuel for an oil engine. In starting it is necessary to heat the vaporizer, but the exhaust gases afterwards keep it at the proper temperature. The carbureter of the gas engine properly belongs under the general head of *vaporizer*, but the term has become restricted to the vaporizer for oil engines.

Variable-Speed Device: See "Gear, Change-Speed".

Vertical Motor: An upright engine whose piston travel is in a vertical plane.

Vibrator: The part of the primary circuit of a jump-spark ignition system by which the circuit is rapidly interrupted to give a transformer effect in the coil.

Vibrator, Master: See "Master Vibrator".

Volatile: Passing easily from a liquid to a gaseous state, in opposition to *fixed.*

Volatilization: Evaporation of liquids upon exposure to the air at ordinary temperatures.

Volt: Practical unit of electromotive force; such an electromotive force as would cause a current of one ampere to flow through a resistance of one ohm.

Voltammeter: A voltmeter and an ammeter combined; sometimes refers to wattmeter.

Voltmeter: An instrument for measuring the difference of electric potential between the terminals of an electric circuit. It registers the electric pressure in volts.

Vulcanization: The operation of combining sulphur with rubber at a high temperature, either to make it soft, pliable, and elastic, or to harden it.

Vulcanizer: A furnace for the vulcanization of rubber.

W

Walking Beam: See "Rocker Arm".

Water Cooling: Method of removing the heat of an internal-combustion motor from the cylinders by means of a circulation of water between the cylinders and the outer casing.

Water Gage: An instrument used to indicate the height of water within a boiler or other water system. It consists of a glass tube connected at its upper and lower ends with the water system.

Water Jacket: A casing placed about the cylinder of an internal-combustion engine to permit a current of water to flow around it for cooling purposes.

Watt: The unit of electric power. It is the product of the current in amperes flowing in a circuit by the pressure in volts. It is $\frac{1}{746}$ of a horsepower.

Watt Hour: The unit of electrical energy. The given watt-hour capacity of a battery, for instance, means the ability of a battery to furnish one watt for the given number of hours or the given number of watts for one hour, or a number of watts for a number of hours such that their product will be the given watt hours.

Welding, Autogeneous: A method of joining two pieces of metal by melting by means of a

blow torch burning acetylene in an atmosphere of oxygen. This melts the ends of the parts and these are then run together.

Wheel, Artillery: A wood-spoked wheel whose spokes are in line with a line drawn vertically through the hub.

Wheel, Dished: A wheel made concave or convex so that the hub is inside or outside as compared with the rim. This is to counteract the outward inclination of the wheel due to the fact that the spindle is tapered and that its outward center is lower than its inner center.

Wheel, Double-Interacting: The mechanism by which two wheels are hung on one hub or axle, the outer being shod with an ordinary solid tire and the inner with a pneumatic tire, so that the weight of the vehicle bears against the lowest point of the pneumatic tire of the inner wheel to give the durability and tractive properties of a solid tire with the resiliency of a pneumatic.

Wheel, Spare: See "Spare Wheel".

Wheel Steering: See "Steering Wheel".

Wheel, Wire: A wheel with spokes made of wire.

Wheel Puller: A device used for pulling automobile wheels from their axles.

Wheel Steer: A method of guiding a car by means of a hand wheel.

Wheel, Steering Angle for: The angle which the steering column makes with the horizontal. It varies from 90° to 30° or less.

Wheelbase: The distance between the road contact of one rear wheel with the point of road contact of the front wheel on the same side.

Wheels, Driving on All Four: The method of using all four wheels of an automobile as the driving wheels.

Wheels, Driving on Front: The method of using the two front wheels as the drivers.

Wheels, Steering on Rear: Method of guiding the vehicle by turning the rear wheels.

Whistle: An automobile accessory consisting of a signalling apparatus giving a loud or harsh sound. Also called a *horn*.

Wind Guard: See "Wind Shield".

Wind Shield: A glass front placed upright on the dash to protect the occupants of the car from the wind.

Wipe Spark: Form of primary sparking device in which a spark is produced by a moving terminal sliding over another terminal, the break thus made causing a spark. Also called *touch spark*.

Wipe-Spark Coil: A primary spark coil with which the spark is made by wiping contact.

Wire Drawing: The effect of steam passing through a partially closed valve or other constricted opening; so called from the thinness of the indicator diagram.

Working Pressure: The safe working pressure of a boiler, usually estimated as ⅙ of the pressure at which a boiler will burst.

Worm: A helical screw thread.

Worm and Sector: A worm gear in which the worm wheel is not complete but is only a sector. Used especially in steering devices.

Worm Drive: A form of drive using worm gears. See "Gears, Worm".

Worm Gear: The spiral gear in which a worm or screw is used to rotate a wheel.

Worm Wheel: A wheel rotated by a worm.

Wrist Pin: See "Piston Pin".

X

X Spring: A vehicle spring composed of two laminated springs so placed one upon the other that they form the letter X.

Y

Yorke, Steering: See "Steering Yoke".

REVIEW QUESTIONS

REVIEW QUESTIONS

ON THE SUBJECT OF

ELECTRIC AUTOMOBILES

PART I

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1. Why is the Edison battery of special interest?

2. What are the advantages of a series-wound motor?

3. Why is the electric automobile essentially a pleasure vehicle?

4. Give a description of the construction of the Edison negative plate.

5. Describe the drum type of controller.

6. What is the standard unit for measuring the capacity of a storage cell?

7. What is the strongest recommendation for an electric car?

8. Make a control wiring diagram.

9. Give a short description of the Arrol-Johnston electric car.

10. Describe the positive plate of the Ironclad Exide type.

11. What are the essentials of an electric motor?

12. State the advantages of worm-gear transmission.

13. What is the office of a shunt?

14. Of what is a battery composed?

15. What are the advantages and disadvantages of Edison storage batteries?

16. How is counter-e.m.f. developed in an electric motor?

17. What is the office of a fuse?

REVIEW QUESTIONS

ON THE SUBJECT OF

ELECTRIC AUTOMOBILES

PART II

1. At what temperature will an electrolyte freeze which has a specific gravity of 1.210?

2. What parts of an electric motor are subject to wear?

3. Which is the corresponding specific gravity for 30° Baume?

4. What is one of the commonest ways of abusing a battery?

5. By what is the power of an electric vehicle limited?

6. What is the lowest limit to which a battery could be discharged?

7. Describe the Fritchle Milostat.

8. Why are solid rubber tires adaptable to electric cars?

9. What should be the specific gravity of the electrolyte when fully charged?

10. Describe the automatic charge-stopping device.

11. The price of one kilowatt of electricity for charging storage batteries is 7 cents; what will 76,560 watts cost?

12. State the constituents of the electrolyte and their proportion.

13. State the cause of low battery power.

14. Discuss the danger of overcharging.

15. What are the dangers of sulphating and how can we guard against it?

16. Describe the different steps necessary in starting an electric car.

17. State the most important point to be observed in the care of the battery.

REVIEW QUESTIONS

ON THE SUBJECT OF

STEAM AUTOMOBILES

1. Define radiation, absorption, conduction, and convection.

2. What is absolute zero? What molecular state does it theoretically represent?

3. Discuss the location of the steam engine on automobiles.

4. Convert 65 degrees Fahrenheit into centigrade.

5. State Boyle's Law.

6. Define force, work, power, and horsepower.

7. Describe and sketch the action of an elementary slide valve.

8. Define British thermal unit.

9. Draw a theoretical indicator card for one-fourth cut-off.

10. Define latent heat. How many British thermal units are absorbed in boiling away a pound of water at atmospheric pressure?

11. Discuss the effect of compression on the indicator card of an engine.

12. Why is the explosion of a stationary boiler so destructive?

13. Define superheat. What is its object?

14. What is the purpose of condensers if used on steam cars?

15. Describe and sketch the Stephenson link valve motion.

16. Describe the Bunsen burner.

17. What is the object of the pilot light?

18. Describe the Ofeldt burner.

19. How are automobile boilers classified?

20. Explain the principles of the fire-tube boiler.

21. In what way do flash boilers differ from the other types?

22. For what purpose are check valves used; how are they constructed?

REVIEW QUESTIONS

ON THE SUBJECT OF

COMMERCIAL VEHICLES

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1. Classify commercial vehicles as to power used.

2. State briefly the advantages of the electric.

3. What methods of motor suspension are used on light shaft-driven delivery cars?

4. Describe rear-axle construction of the 2-ton Commercial.

5. What are the peculiar advantages of the Couple-Gear truck?

6. What transmission is used on the Walker electric?

7. Why are safety devices installed on most all up-to-date trucks? Describe action of the charging circuit-breaker.

8. Where is the controller located in the Baker?

9. How many plates are used per cell in light delivery wagons?

10. What are the dimensions and horsepower of motor used on the Autocar delivery wagon?

11. Give bore and stroke of motors used on the White 5-ton trucks; on the Pierce Arrow; on the Locomobile; on the Vulcan.

12. What type of radiator is usually used on trucks; why is it used?

13. Sketch the White sight-feed lubricating system.

14. Explain the action of the Pierce centrifugal motor governor.

15. Describe the Jeffery Quad.

16. Explain the principle of compensating spring support.

GENERAL INDEX

GENERAL INDEX

In this Index the **Volume number** appears in roman numerals—thus: I, II, III, IV, etc., and the **Page number** in Arabic numerals—thus: 1, 2, 3, 4, etc. For example: Volume IV, Page 327, is written, IV, 327.

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